COLLERS 2

PM FROM WSP TO THE SWEDISH TRANSPORT ADMINISTRATION

2022-12-13

COLLERS 2

PM from WSP to the Swedish Transport Administration

CUSTOMER

The Swedish Transport Administration (Trafikverket)

CONSULTANT

WSP Advisory

WSP Sverige AB
121 88 Stockholm-Globen
Besök: Arenavägen 7
Tel: +46 10 7225000

wsp.com

CONTACT PERSONS

WSP Sverige AB
Matts Andersson, matts.andersson@wsp.com

Trafikverket
Roger Ullström, roger.ullstrom@trafikverket.se

WSP ASSIGNEMENT NUMBER
10315877

AUTHORS
Matts Andersson, Fredrik Widegren, Erik Johansson, Lars Sundvall, Anders Nyström, Marcus Eriksson, Maria Kättström, Henrik Josefsson, Marie Holmlund, Martin Lagnerö, Klara Paulsson, Marie Holmlund, Christopher Roberts, Niklas Strömdahl, David Gullberg, Bror Lundbergh, Per-Olof Jönsson, Stefan Uppenberg, Marcus Eriksson, Eva Wadström, Lif Nelander

DATE
2022-12-13

CONTENT

Introduction

Background

In January 2018, German and Swedish research organizations conducted a joint study on Electric Road Systems (ERS) with the aim to:

- Provide assessment of different ERS concepts
- Assess ERS markets, business models and financing strategies
- Research requirements for international ERS interoperability
- Investigate the impact of ERS on the energy system and the environment
- Recommend necessary policy actions to spur ERS introduction
- Identify a suitable ERS freight corridor between Sweden and Germany

The Swedish-German Research Collaboration on Electric Road Systems (CollERS 1) was completed during the spring of 2020. The project consisted of core members from the Swedish Research and Innovation Platform for Electric Roads (RISE, Chalmers University of Technology, KTH Royal Institute of Technology, Swedish National Road and Transport Research Institute (VTI) and the Swedish Transport Administration) and the two national German research projects (Roadmap OH-Lkw and StratON), including the four German partners Öko-Institut e.V, Ifeu, Fraunhofer IEE and Heilbronn University of Applied Science.

Following CollERS 1, Sweden and Germany agreed to continue the collaboration in the field of ERS. France is planning to join more actively in the autumn of 2022. The overall purpose of CollERS 2 is to increase the common knowledge about ERS. The Swedish Transport Administration has procured WSP to manage, coordinate and perform CollERS 2.

The German team consists of researchers from Fraunhofer ISI, Ifeu, IKEM, Verkehrspolitik & Raumplanung and Öko Institute. France is, at the time of writing this report, about to join. The active partners from France will be Université Gustave Eiffel and Carema.

WSP's assignment

WSP is assigned by the Swedish Transport Administration to:

i) Manage and coordinate the collaborative project CollERS 2 between Germany and Sweden, regarding electric roads
ii) Perform analysis and technical assessment of electric road technologies

The analysis and technical assessment consist of:

- Analysis of the ERS techniques based on technological readiness levels (TRL), potential for greater implementation and impact on the environment. Analyse TRL aspects of battery electric vehicles (BEV) and hydrogen vehicles
- Analyse the practical and technical perspectives for operation and maintenance.
- Analyse ERS impacts on, and need for, traffic management, operation, and facility monitoring
- Life Cycle Analysis (LCA) and Life Cycle Cost Analysis (LCC)
- Analyse technical and legal aspects of interoperability
- Analyse technical aspects of energy measurement and billing
- Analyse the conditions for implementation along TEN-T corridors
- Analyse socio-economic aspects
- Analyse the effects on the economy of an investment in ERS
- Analyse country specific conditions affecting ERS and non-ERS technologies

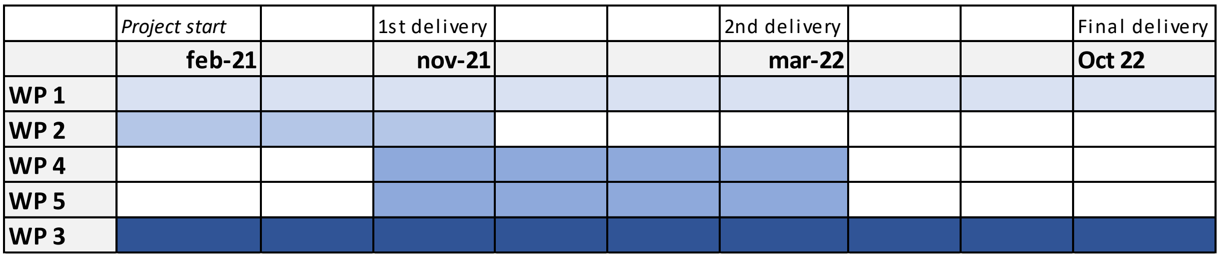
Deliverables from CollERS 2

Discussions in the spring of 2021 addressed how best to coordinate the collaboration. A decision was made that the main deliverables from CollERS 2 will be a series of discussion papers. The input to each discussion paper will be discussed at a workshop and the papers will be co-authored by WSP and the relevant German contributors. The Swedish and German governments have both given instructions that deliverables from CollERS 2 should be short, hence each discussion paper is around 10-15 pages. The discussion papers will cover:

1) Technology assessment (completed)
2) Regulatory issues (completed)
3) Corridor analysis and socioeconomics (planned for November/December 2022)

Since the official deliverables must be short, and topics from the Swedish work assignments are not entirely covered in the discussion papers, the Swedish Transport Administration and WSP have decided that WSP's work will not only feed into the discussion papers, but also be reported in the form of this PM. The primary target group for this PM are people at the Swedish Transport Administration who work with these issues and the German and French CollERS participants. Since the target groups are experts, the writing style assumes prior knowledge of the topics. Since an important purpose of this PM is to transfer knowledge about work done in Sweden to foreigners, some texts will not be new to a Swedish audience.

The discussion papers are often published (and the corresponding work packages end) long before the deadline for the entire project. WP 2 in this PM was delivered and approved by the Swedish Transport Administration in November 2021; similarly, WP 4 and WP 5 were delivered in Mars 2022. The only new deliverable in this version of the PM is WP 3 (WP 1 covers project management). Below is a summary of the overall duration and delivery of respectively WP over time:



	Project start		1st delivery			2nd delivery			Final delivery
	feb-21		**nov-21**			**mar-22**			**Oct 22**
WP 1	■	■	■	■	■	■	■	■	■
WP 2	■	■	■						
WP 4			■	■	■	■			
WP 5			■	■	■	■			
WP 3	■	■	■	■	■	■	■	■	■

Since ERS is a fast-moving area, and several WP:s were finalized and reported prior the project end, new information may have emerged in these areas, that are not included in this PM. This is especially critical in WP 2, as this WP was reported first (almost one-year prior project end) and is an area with high rate of innovation and progression at the time, something the reader is asked to keep in mind reading these sections further on.

Although the assignment was not intended to provide an overall judgement or plan for ERS implementation, various aspects covered in the PM offer relevant input in this regard. The detailed structure of the assignment also has implications for how this PM is written and meant to be read. There are no overall conclusion chapters and no text transitions between chapters. Reading the report from cover to cover would be a challenging task; as such, readers are advised to do a deep dive into areas of interest.

WP 2 Technology assessment

In CollERS 2021-2022, WSP has been assigned to do a technology assessment of ERS (WP 2), including several aspects and perspectives covered in separate Work Packages (WP). The work packages that have been included in the assessment are:

- WP 2.1 Technology maturity (TRL, potential for larger implementation)
- WP 2.2 Operation & Maintenance
- WP 2.3 Traffic Management Systems
- WP 2.4 LCA / LCC
- WP 2.5 Standardization and Interoperability
- WP 2.6 Energy and billing
- WP 5 Swedish prerequisites for BET and FCET

This technology assessment has been divided into two separate parts; where part one (see chapter *Evaluation of Technology Readiness Level (TRL))* isolated covers a TRL-analysis of the four different ERS-suppliers (Siemens, Elonroad, Evias, Electreon) and part two (see chapter *Evaluation of technology maturity*) include a broader analysis of technology maturity based on inputs from WP 2.1-2.4 and WP 5. Based on findings from each WP, a few criteria/aspects have been identified per WP in this part to evaluate the degree of additional complexity or its potential that a specific criteria/aspect entails for respectively ERS-technology. All criteria/aspects have then been converted into an overall matrix, to support a better overview of the result.

The reader is reminded that WP 2 was reported and approved in late 2021 and that ERS is a fast-moving area. Parts of the result were published in discussion paper 1.

WP 2.1a Technology maturity

Evaluation of Technology Readiness Level

The TRL scale was initially invented by NASA in the 1970s and was further developed in the 1980s and 1990s. Other organizations, such as the U.S Department of Defense (DoD), have continued the development of the framework to today's established method of Technology Readiness Assessment (TRA) which is used to estimate the maturity of a technology system for a given application.

Applying TRL to ERS

Findings from the literature review indicate that there is very limited previous work made on the assessment of TRL for ERS. However, on a complete ERS system level, TRL is mentioned and graded in some reports, but by breaking the ERS down into subsystems, there has only been one scientific article written by Martin G. H. Gustavsson and Magnus Lindgren (Gustavsson & Lindgren, 2020b) that covers this aspect. Hence this article has been identified as particularly relevant for this assessment. In that scientific article, the authors applied the TRA- and the TRL scale on an entire ERS-system (including several subsystems) for respectively ERS-technology (overhead catenary lines, conductive and inductive).

The starting point for this TRL-assessment has been to make use of relevant parts from this article. But by dividing each ERS-technology into several subsystems which then individually can be graded with a TRL, this PM aims at taking the TRL-assessment to a more detailed level. Hence, the same definition of TRL levels was initially used in this PM to assess the TRL of different subsystems of the ERS. However, once the TRL definitions were applied to different subsystems it became clear that the definitions needed to be slightly adjusted to be able to use the same definition on the very different subsystems. The following TRL definitions have been developed and used for this part:

- TRL 1. Basic principles observed and reported.
- TRL 2. Technology concept and/or application formulated.
- TRL 3. Analytical and experimental critical function and/or characteristic proof of concept.
- TRL 4. Component and/or breadboard validation in laboratory environment.
- TRL 5. Component and/or subsystem **validation along test track** and subject to any realistic weather condition.
- TRL 6. Demonstration of the subsystem in an environment where **the vehicle is propelled** by power from ERS equipment **along test track** and subject to any realistic weather condition.
- TRL 7. Demonstration of the subsystem in an environment where the vehicle with prototype power receiver, running **along a public road** during any realistic weather condition, and propelled and charged by power provided by a prototype power transfer subsystem installed in vehicle and deployed along the public road. The subsystem is **working sufficiently for its application** (e.g., meeting the requirements on operational speed, accuracy, managing several vehicles, and power supply in kW).
- TRL 8. The subsystem has proven to **work in its final form**, under expected conditions. In almost all cases, this TRL represents the end of true system development.
- TRL 9. Once the subsystem is deployed at or for a customer, the exposure to unexpected conditions might lead to a need for additional adjustments of the system. Once these are managed successfully, the subsystem could for that context and conditions be defined to have reached the highest maturity of TRL 9.

It is also important to differentiate between incremental product improvements (increase performance) which do not necessarily influence the level of TRL and more radical redesigns of the system in order to manage insufficient technology functions, which could lower the level of TRL.

TRL-Matrix

As ERS consist of several subsystems, this assessment of TRL has divided the overall ERS into the following subsystems, which individually have been assessed with a TRL-grading for respectively ERS-technology, see Table 1.

Table 1. Definition of the subsystems used in this TRL-assessment and what is included in them.

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 short or long term. This could hence impact the TRL for each subsystem. 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. This is however not the case in this assessment. There could also arise situations were 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, and in such cases this is evaluated as a part of the specific ERS-solution rather than a generic technical solution that could be applied to all ERS technologies. This is partly motivated by the fact that the choice of technical solution is part of the selected ERS architecture and partly by the fact that the evaluation and requirements for the higher levels of TRL are based on that the technology is being tested in its real environment/application.

See Figure 1 below, to understand how the evaluated subsystems above refer to the Swedish Transport Administration’s previous definition of components and services of an ERS.

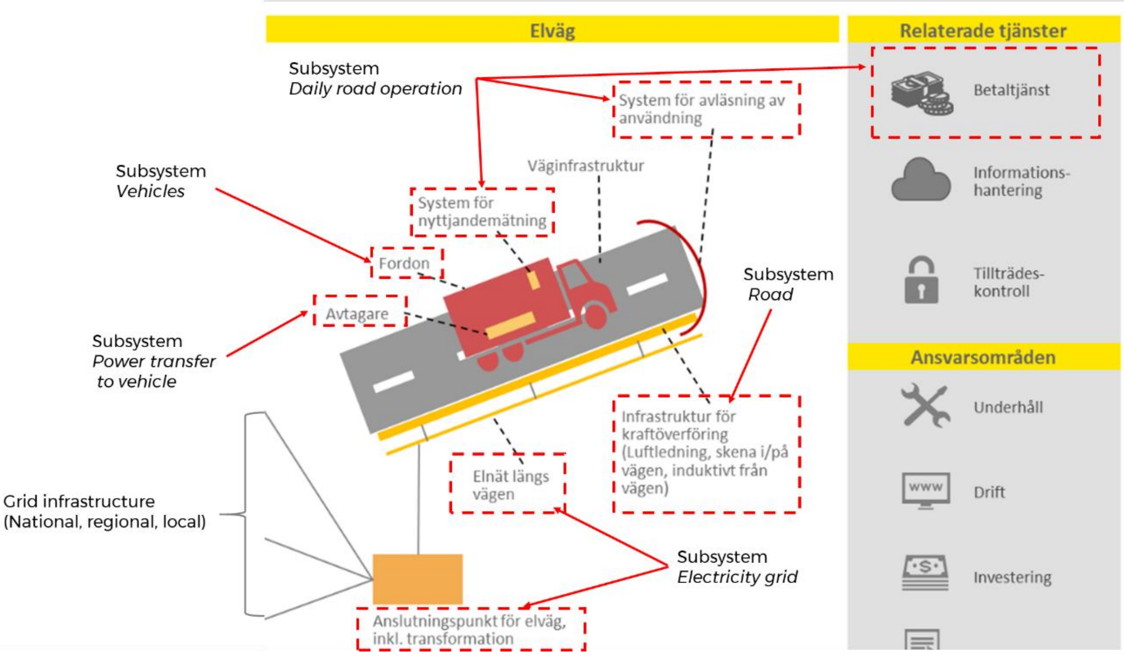


Figure 1. This assessments subsystems in relation to the Swedish Transport Administration's ERS-system definition. In this figure Swedish terms have been translated to corresponding English terms.

The TRL assessment in this chapter was carried out by WSP and is primarily based on the three following sources of information:

1. Desktop research on technical descriptions of respectively ERS-technology + other relevant sources of information provided by the Swedish Transport Administration
2. In-depth interviews with one or several representatives from each ERS-supplier + complementary follow-up questions to ensure same aspects were covered for each ERS-supplier
3. Insights and lessons learned from the demonstrators (through the Swedish Transport Administration's documentation)

All information gathered throughout the assessment are summarized in the matrixes further below, where the information is presented for each ERS-supplier per subsystem. Based on these data, WSP have graded each subsystem with a corresponding TRL number according to the definitions presented above.

The outcome of WSP's TRL assessment is illustrated in Table 2, where Figure 2 describes the color-scale applied to the matrix. Note that the assessment was carried out in the spring of 2021 and finalized by December 2021. New information and data that have emerged after this has not been included in the evaluation below.

Table 2. Grading of TRL for respectively ERS technology.

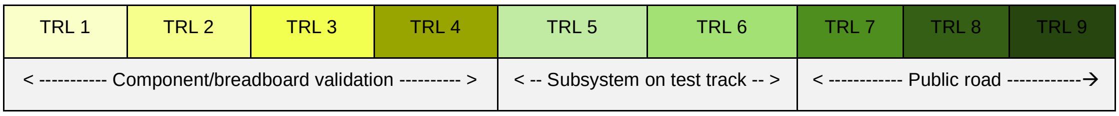
Supplier **Subsystem**		**Siemens eHighway**	**Elonroad**	**Evias**	**Electreon**
Electricity Supply		TRL 8	TRL 7	TRL 7	TRL 7
Road		TRL 7	TRL 7	TRL 7 TRL 4	TRL 6
Power Transfer to Vehicle	< 60 km/h	TRL 8	TRL 6	TRL 7	TRL 6
	> 60 km/h	TRL 8	Not tested	TRL 7	TRL 6
Daily Road Operation	Energy Measurement	TRL 7	TRL 6	TRL 5 TRL 2	TRL 6
	Vehicle Identification	TRL 6	TRL 6	TRL 6 TRL 3	TRL 7
	Billing and Payment Solutions	TRL 6	TRL 2	TRL 2	TRL 4
Vehicles	Truck	TRL 8	Not tested	TRL 7	TRL 6
	Bus	Not tested	TRL 7	Not tested	TRL 7
	Van	N/A	TRL 6[1]	Not tested	TRL 6
	Car	N/A	TRL 6[2]	TRL 6	TRL 6

---

[1] Limited to TRL 6 as no dynamic charging has been demonstrated.

[2] The car has been propelled and charged dynamically, but in low speeds (< 50 km/h), hence not fulfilling typical operational speed for TRL 7.

According to the following color-scale:



TRL 1	TRL 2	TRL 3	TRL 4	TRL 5	TRL 6	TRL 7	TRL 8	TRL 9
< ---------- Component/breadboard validation --------- >				< -- Subsystem on test track -- >		< ------------ Public road ------------→		

Figure 2. Color-scale for the TRL assessment.

From Table 2 it can be concluded that the TRL of different subsystems seems to differ both within a single ERS-technology as well as within a specific subsystem in comparison between all the ERS-technologies. During interviews with the suppliers, it has become clear that the technologies are currently facing slightly different challenges in both similar but also different subsystems. From the TRL-assessment it can be concluded that the subsystem *Electricity Supply* is the one with the highest TRL and the subsystem for *Billing and Payment Solutions* are the one with the lowest TRL.

Up till today, different ERS-technologies seem to focus on slightly different vehicle applications in their demonstration tracks. Siemens eHighway seems to be the technology with both the highest TRL in general and the supplier that is most progressed in terms of getting ready for a process of industrialization and scale-up of the system. This is mainly because the technology is based on conventional components (over headlines) and systems from road tolling systems (e.g. European Electronic Tolling Service, EETS, and On-board Units, OBS) that are already in commercial applications. Hence, the technology is also the one with far less innovation in terms of its capabilities to add new functions to the system, for example, digital solutions such as real-time data, etc.

For more information regarding the assessment of individual cells in Table 2, see the following matrices, where each matrix covers respectively subsystem for all ERS-technologies. Note that the main part of the summary below is documented information that was provided to WSP in dialog with the representative of each ERS-technology (the interviews held with each ERS-supplier) as well as the complementing information gathered through the follow-up questions with each supplier. The assessment and reasoning regarding final TRL grade for each subsystem is solely made by WSP.

Subsystem - Electricity supply

Subsystem	**Electricity Supply**
Siemens eHighway	Siemens intends to use its product Packaged Power Solutions (PPS) for the substations. The number of PPS required will depend on several aspects such as the number respectively frequency of vehicles as well as their operational speeds. There are today two PPS (1MW each) on the Elisa test track feeding the 2 x 5 km test track. An extension of the track is planned (17 km) and for this application, another PPS will have to be installed. For a larger implementation, the number of PPS will be additive (depending on the power requirements of the final system), hence no redesign of the subsystem will be required. If the system needs more power, another PPS could for example be installed between two already installed PPS. In Germany, PPS does not have to be in the road area, they have for example been placed in rest areas, under a bridge, and next to the driveway for the highway. If there are already safety barriers for the required poles, it might still be convenient to put the PPS close to them. They are usually placed above ground. In Sandviken the test track was designed for 750V DC, although tests were run at 600V DC. According to Siemens, that system could transfer 540 kW (900A, 600 V DC) per substation. The next step is to increase the voltage to 1200 V, which will require slightly adjusted components in the substations. According to

	Siemens, such technology has already been tested in railway applications. As the substation is not unique for the ERS facility, the application in the railway is considered sufficient to not impose a need to reduce the TRL assessment once the substation is applied to the ERS. In Sandviken, a grounding concept concerning safety was still under development which could argue to reduce maturity to TRL 7. As there are currently ongoing tests with the substations in operation on the test tracks in Germany, the system has reached TRL 7. These stretches have also been deployed several years after Sandviken, and as Siemens have not mentioned that grounding is still a challenge this does not impact the TRL longer. The final configuration of the number of substations (PPS) will depend on several factors such as how many vehicles need to be supplied simultaneously and to what power levels. From a technical point of view, no radical redesign of the PPS is required as additional units are just added or some components in the PPS are adjusted. The subsystem can therefore be seen to have reached its final form and hence TRL 8 in this assessment.
Elonroad	For Elonroad, the substations are planned to be placed 0-20 meters from the road, even though the distance technically could 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. From a technical point of view, the same solution, although a smaller subsystem (0,3MW), has been installed and tested on the public test track in Lund at speeds up to 50 km/h. If the system is scaled up to 3 MW, the length of the rails would become a bit shorter and a few more rectifiers need to be added. The substations are preferred to be placed above ground. For scale-up of Elonroad's technology, the dimensioning of substations (number, distance, etc.) might differ from the test track, hence the subsystem has not been proven to work in its final form, TRL 8. Operational speeds above 50 km/h have not been tested on public road, but as the electricity supply from a technical point of view is not primarily dependent on individual vehicles speed (as long as there is enough power), the subsystem *Electricity Supply* could be argued to have reached TRL 7.
Evias	The ERS from Elways requires substations every 1-4 km depending on power and traffic intensity. For example, 4 km is required if there is one truck per 1 km and 200 kW per substation. Increasing the power to 800 kW per truck and two trucks per 1km lowers the distance to 1 km. One substation supply both lanes with power and should be placed above ground and outside the road area. Management units need to be placed at approximately 200-meter intervals and feed four 50-meter sections. These can be placed either in the road area, which will require additional barriers or outside the road area (safety area). For larger roads, management units will be needed on both sides of the road. The substation that was used at eRoadArlanda is the same as if the system would be scaled up, although it might have to be dimensioned a bit differently depending on the requirements of power output etc. This would be made with conventional technology such as transformers, switches, and cables, hence having less impact on TRL. The road is however fed with alternating current (AC) according to the Swedish Transport Administration, but it will likely be

	changed to direct current (DC) in the future. Depending on the impact of such a change, this could lower the TRL. As the 2 km test track on the public road outside Arlanda was built in the autumn of 2017, the system has been tested extensively with a heavy truck in operation. As the subsystem *Electricity Supply* from a technical point of view does not need to be significantly redesigned once scaled up, this subsystem can be seen to have reached TRL 7 (for AC feeding). The impact of switching to DC could however result in lowering the TRL.
Electreon	Electreon's subsystem *Electricity Supply* needs one substation every two km (one substation per km and direction, as one substation supplies electricity to both directions). The substations are not placed within the road area. Except for substations, there is also a need for management units along the ERS, which are placed within the road area. These units can either be placed above or below ground, depending on local circumstances. If there is for example already a high level of safety barriers (H4), the management unit does not need to be placed below ground. Currently, there are national differences between management units, for example, the ones placed in Gotland compared to the ones in Italy, mainly because of preferences between DC respectively AC. From a technical perspective, the substations are basically working in its final form corresponding to TRL 8, however, the additional need for management units along the road is adding a new element in the road area which is raising some concerns. For example, there is both a solution for units above and below ground, and the additional need for maintenance, including requirement on access once every year is not investigated in depth and hence quite immature. Since the requirements imposed on the different solutions are unclear, including access, maintainability, etc., the final form of the system can be questioned, hence limiting the subsystem to TRL 7.

Subsystem - Road

Subsystem	**Road**
Siemens eHighway	There is no impact on the structural road body with Siemens overhead lines. However, there is a need for additional barriers due to the poles. When the test tracks in Germany were deployed with Siemens's technology, some parts of the stretches already had barriers meanwhile other parts had previous needs to be renovated, which then was done within the project. For further scale-up in Germany, there is currently a need to define impact class of the pillars as they are deployed along the road. This is primarily issued by the road operator (in Germany highway authority). Required barriers are then defined by this class. Siemens have tried to draft standards for this, but has not yet succeeded, partly due to challenges of national differences for this aspect. As the demand for barriers has been assessed and upgraded accordingly on current ongoing test tracks, the subsystem could be seen to have reached at least TRL 6. As the test track on public road both in Germany and Sweden (Gävleborg) are on highways, the corresponding requirements on barriers for

	that speed-range have been managed successfully. As the technical complexity of barrier is quite low, the subsystem could be seen to have also reached TRL 7, even in highway context. To reach TRL 8, the subsystem needs to be closer to its final form, including progressing the work with defining impact class and corresponding requirements for barriers.
Elonroad	Elonroad’s latest rail-version of its ERS-concept is a submerged rail in the road which have been deployed on the test track in Lund and running in operation for approx. one year now, covering all weather seasons. To install it, a groove is needed that is 6 cm deep and 40 cm wide, where the technology is then installed, and the groove is asphalted again. As switches and internal substations are incorporated in the Elonroad rails, feeding cables (including digging out in the road body at right angle from the direction of travel) is only needed every 1,5 km. There is no need for additional barriers according to the supplier, and the ERS is equipped with several safety functions such as shake sensors and can provide additional data that is not collected today (for example local temperatures). There is also no need for additional cameras (supervision), and electrical safety is built in. Elonroad is planning to perform tests where there is ground frost and the road moves significantly (changes height). Even though the maximum permitted operational speed on the public test track is limited to 50 km/h, there is no general need for additional components nor redesign of the ERS to reach higher speeds. Hence, the subsystem *Road* can be seen to have reached TRL 7. The Elonroad system has evolved quite radically over the last years, with the latest rail-version being submerged in the road. Hence it is hard, based on only approx. one year of testing, to conclude if the system now has become closer to its final form or if it will be redesigned again. To reach TRL 8, the subsystem must be proven to work in its final form, under expected conditions and this will be the next step to fully reach TRL 8. This will also include proven feasibility of higher operational speed of the truck.
Evias	Evias ERS-technology is excavated into the road body, and in addition to this the technology need drainage out to the ditch. During their approximately two years of testing at the public test track, the rails needed to be changed into a newer version (partly because it got bent from solar heat during exceptionally heat summer days). Elways recently developed a new design of the rail which has been installed into their test track (no public road) on 25th October 2021. The biggest difference is that the new rail is dimensioned for 800 kW, which was achieved by eliminating a small weak spot in the earlier version. According to Elways, there should be no need for additional barriers and the substations should preferably be places so far away from the road that they do not need barriers either. The older version of Evias rail has been demonstrated by propelling and charging a truck by power from the ERS along the public test track at Arlanda. The operations have been performed in all kinds of weather and seasons (more than 2 years) and in speeds up to 80 km/h for the truck. Therefore, it could be seen to have reached TRL 7 up to that speed. However, as Elways have developed a new version of the rail that was installed on their test track (outside public road) as late as 25th October 2021, there has

	not been enough time to demonstrate the vehicle along the test track and to have it subjected to any realistic weather condition. Hence it is challenging based on current knowledge if this new version limits the subsystem to TRL 4, as it has not been subjected to all weather conditions, or if the improvements/changes are so small that the system could still be seen to have reached TRL 7. If the system is deemed to be TRL 4, it will however most likely reach TRL 6 as soon as it has been subjected to any realistic weather condition.
Electreon	Management units should be placed below ground if there are not sufficient barriers already in place, in other cases there will be a need for additional barriers. The power electronics need maintenance once every year, hence access to the management units will be required. There is currently no routine or process for this, but Electreon claims that this probably could be done in the same way as maintenance of road cameras. Hence, a TBA car is probably required. Today the maximum transferred power is 125 kW, but to meet the Swedish Transport Administration's functional requirements the power needs to be increased. The technical design of the system works in such a way that the system is repeated every two meters, hence the overall design should not differ between demo, test tracks and a larger scale-up phase. Tests in up to 80 km/h have been performed on the public test track at Smartroad Gotland, and the system have been in operation for over a year now. However, as the transferred power need to be increased, the subsystem has not reached its final form nor proved to work sufficiently for that application (trucks). Hence, the subsystem can be seen to have reached TRL 6. To reach TRL 7, the system needs to fulfill the required transferred power needed of a truck running on an ERS. If the system in the future need to be significantly redesigned in order to reach higher transferred power, the TRL would become lower for the subsystem.

Subsystem - Power transfer to vehicle

Subsystem	**Power Transfer to Vehicle**
Siemens eHighway	The Siemens technology have been tested on public test tracks both in Sandviken (finalized) and on German public test tracks (ongoing) in full high speed, which according to Siemens makes a big difference to users if there are any limit in performance compared to vehicles used today. As the Siemens technology has been tested extensively since the opening of the ERS in Sandviken in 2016, the receiver (pantograph) is currently in its third generation, of which the last two have been in use by commercial operators. According to Siemens the pantograph has reached a form where it is ready to be industrialized, including that the design is reliable and operational. The industrialization process has started together with Continental and focuses on simplifying the assembly process and reduction of costs. The wear on the pantograph has earlier been identified as challenging, example based on the Sandviken test track. According to Siemens, the wear on the pantograph is mainly on the carbon strips that are in direct contact with

	the overhead contact lines. Their wear and tear are so low that a replacement only needs to happen in conjunction with the regular truck maintenance. In the field trials the wear is meeting the expectations. During the project in Sweden (Sandviken), it was at that time already described, that special conditions had caused a higher wear and that pantograph was a former version which had been manufactured and used in 2016 – five years ago. The trucks in the field trials do have different power train configurations, which determine the used power. The current trucks in Germany mostly withdraw 150kW (120kW for propulsion and remaining power for charging a relatively small battery pack). The eHighway system (infrastructure and pantograph) is capable to transfer 350kW per truck. In future slightly higher power transfers would also be possible according to the supplier. The Siemens eHighway technology has been tested extensively on public test tracks both in Sweden and Germany, including running the trucks in operational speed of a highway. The power transfer seems to be a bit limited (only 150 kW), but from a technical point of view the infrastructure and pantograph supports higher powers up to 350 kW per truck. As the pantograph is in its third generation and currently in an industrialization process together with the fact that the system seems to work sufficient for its application (based on extensive testing) the system can be seen to have reached TRL 8, hence representing the end of the true system development of this subsystem.
Elonroad	The bus that runs on the public test track currently receives 200 kW, but Elonroad aims at reaching 300 kW in the future. The receiver is currently in contact with one switch at a time, but by making the receiver longer and hence get contact with two switches the power is estimated to be increased to 300-400 kW. The operational speed of the bus has reached 60 km/h. There is an ambition to test a heavy truck in speeds up to 100 km/h in a near future, but currently they lack such a vehicle. The power receiver for the submerged rail requires a bit more advanced system than for the one on ground, and the tests of this receiver has just started. The biggest difference is that the one for the submerged rail is much smaller and moves horizontally according to the rail. The limited speed on the public test track (40 km/h) is somehow hampering the ability to meet the requirement for TRL 7 of “running at typical operational speeds” for a bus or a heavy truck in speeds above 40 km/h, or at least extensive testing. Moreover, as the new receiver has just started to be tested and there is a goal to increase the power to 300 kW, the system is defined to be limited to TRL 6.
Evias	The power receiver has been tested for several years during multiple seasons on the public test track at eRoadArlanda. Next step in the development is to refine the system for production in larger scale, including optimize for production and price as well as impact depending on demand for power output etc. In the eRoadArlanda project, the ERS provided the truck with 200 kW, but Evias are aiming to increase the power to 800 kW. For this, a new receiver has been developed and tested on their test track (not public) with transferred power up and beyond 800 kW to the truck. The new receiver is compatible with

	both the old and the new rail, but as the power was increased in the system the receiver had to be adjusted. As the system is modular, this can be managed by making the receiver longer, hence there is no need for a radical redesign of the subsystem. As the subsystem *Power to vehicle* has been tested extensively on the public test track at eRoadArlanda, the subsystem could be seen to have reached TRL 7. As the operational speed is rather limited by the allowed road speed on the section (70 km/h), rather than limited by the vehicle or power received, reaching higher speeds seems to be no limiting factor. As the new receiver is only made longer, it is deemed to not lower the TRL even though it has not been tested on the public road.
Electreon	During the initial tests in 2020 and up till today, receivers with 25 kW has been tested, although Electreon has an ambition to increase the power further on. As the system is modular the truck uses five receivers (125 kW), and the bus uses three receivers (75 kW). For the application of heavy trucks, Electreon's current level of transferred power do not meet the functional requirements set by the Swedish Transport Administration, hence limiting the subsystem to TRL 6 for speeds both below and above 50 km/h. To reach higher TRL, the system needs to increase its transferred power to fulfill the functional requirements.

Subsystem - Daily road operation

Subsystem	**Daily Road Operation**
Siemens eHighway	On the German public test sites, energy measurement units have been installed in the field trial vehicles. Proven energy measurement components are used, identical with those in charging stations and that are used for payment processes in other applications. As the measurement units are in the trucks (at the user side), the usage and certification of the systems is easier than in other applications according to Siemens. Hence, they are in discussions with the energy regulators to ensure that the system fits to the requirements and maybe certified according to European measurement law as well. According to Siemens, the energy measurement for their system is tested in its final form at full speed and at full energy transfer, hence Siemens has no intention on look for solutions that do not require vehicles to be equipped with the meters. Siemens state that, as the measurement law for example requires that the user has a clear display of the consumed energy it makes a lot of sense to measure it on the vehicles. In a system where the user moves "through the network", that would not be possible if the energy metering is at the infrastructure side. Furthermore, they state that the installation at the vehicle allows a continuous metering of the energy over longer time (several minutes). This allows a high accuracy and a minimization of measuring faults. In systems where the consumed energy is measured at the infrastructure side only for fractions of a seconds such high accuracy cannot be achieved. The metering at infrastructure side is considered as verification measurement and for statistics only according to them.

	In the field trials in Germany a geo-fencing application is used for vehicle identification. This allows to enable and disable vehicles only for specific eHighway installations, just like the European Electronic toll Service (EETS) On-Board Unit (OBU). Those tolling on board units do have their own ID Number and in the Back office this number is matched with the license plate of the vehicle. Through that system it is possible to enable the vehicle only for such stretches / regions / countries where they have a valid contract for. The identification system for the ERS relies on satellite data, where the system is tracking the GPS positions of the vehicle. Based on that information the driven distance is calculated in the back office. Number plate recognition cameras are not required for the system. Each PAN will get access to the track trough the enable device. Based on the contract conditions the PAN will be enabled for a certain time period as well as for the dedicated tracks. The location of the truck is repeatedly checked by the OBU/enable device and compared with the dedicated tracks. This is done at least second by second (exact figures need to be checked separately). The access control will be managed centrally from the access control tool (Back Office System). In this tool a Mobility provider can give permission to the vehicles to use the eHighway for defined time periods as well as different eHighway sections. This system is already used for satellite based tolling applications (e.g. in Slovakia) with ten thousand of vehicles. Regarding billing and payments solutions, Siemens has within the project Amelie (public funded research project) designed a system which collects the consumed energy from the vehicle and then the back-office system provided creates a DEMO billing. The used OBU and back-office system are those used in tolling applications and are therefore according to Siemens already suitable for “real world billing and payment solutions”. Next steps for an operational system, requires some further data security measures in the communication between energy meter and OBU needs to be incorporated (to ensure an end-to-end encryption), the aggregated data sets need to be transfer to the defined mobility service provide (which is a common interface like in tolling projects) and the overall systems need to be approved by the mobility provider and according to the local calibration law. The Amelie-project ended last summer, but in the ongoing follow-up project AMELIE II the described data security measures are incorporated so that the system complies with the German calibration law. After that modification, the system will be used again on the test track in Hessen for some vehicles and time. The Back Office will supply the capability to provide data for following user groups: Transportation company, eHighway Operator and Energy provider. According to Siemens, an operational set-up with reaching TRL 8 or TRL 9 can be quickly reached after definition of the applicable mobility service provider and applicable legislation for ERS usage fees. For all three systems (energy, identification, billing), Siemens state that they use proven technology of the EETC and/or from charging stations that are in operation in the market. These systems conform with EU-wide data security regulation. The systems have been demonstrated on test track and with field trial vehicles, for example in the Amelie-project. It is quite difficult to assess how well the energy measurement units works but based on the facts stated by Siemens above the subsystem seems to have

	reached TRL 7. As the system design is strongly based on EETS (which currently only covers the Oresund bridge in Sweden), an in-depth understanding of how well such a system fits or do not fit into the Swedish context, including corresponding changes that may be required, is needed to grade it as TRL 8. Based on solely the ability to identify and give access to a vehicle, the subsystem for vehicle identification seems to have also reached TRL 7 based on the same reasoning as above. From WSP's perspective, the system seems however rely on that all vehicles have an OBU when Siemens described it, which might not be the case. Hence, it is not quite clear how the system manages and prevents vehicle that try to cheat the system (for example has a modified "black market" pantograph but no OBS) from getting access to the ERS. WSP suggest that this needs to be further analysed and managed to conclude if the system needs to be modified to working sufficiently for its application, hence reaching TRL 7. The subsystem Vehicle identification is therefore currently limited to have reached TRL 6 based on the facts conducted in this work package. A prototype system for billing and payment solutions have been tested in the Amelie-project, including creating demo billing. There are however still some planned activities that need to be finalized according to Siemens before the system reaches the higher TRL's. These activities are partly planned to be tested in the Amelie-II-project, hence the subsystem for Billing and payment solutions is currently limited to TRL 6.
Elonroad	Energy measurement, vehicle identification and access to the ERS is built-in to the Elonroad technology through the rails and the receivers. Energy is currently being measured both in the rails and the vehicle at the public test track in Lund and can be allocated to separate vehicles, even though there is only one bus operating currently. This is mainly enabled by allowing to measure energy for each incorporated switch in the rails. The same logic goes with identification and access to vehicles, which also is currently being tested and can be made on an individual vehicle level. An additional external system for this could also be added if required, but not needed from a technical point of view. From interview with the supplier, a need to tune the energy measurement to become more accurate have been identified, hence the system has not reached its final form yet, TRL 8. Some errors originate from variations in the circuit boards which can be compensated by first calibrating them and then convert this into a software that manage them. Furthermore, the system uses a central computer to manage vehicle ID and energy consumption which need to be further developed (primarily software) to manage more than one vehicle simultaneously. The system is also prepared to in the future share relevant information to other actors (for example for billing solutions), but this have not yet been fully developed nor tested on the public test track. How much that remains on the technology development to be finalized has not been assessed in this part as the TRL is limited by the fact that they are not fully developed yet. As both energy, identification and access are being tested on the test track at Lund, the subsystem could be argued to have reached a TRL 6 or 7, except for the payment and billing solutions. The limited operational speed of 50 km/h is considered to have less impact on the subsystem's technical capability.

	However, as there still is a need to tune the energy measurement system to become more accurate and there is also a need to improve/develop the subsystems for energy measurement and access to manage several vehicles successful, these subsystems are defined to be limited to TRL 6. Even though there are some activities aiming to prepare the system to share data for payment and billing solutions in the future, the early development stage seems to be focused on critical functions and proof of concepts, hence limiting the subsystem to TRL 3.
Evias	Once a vehicle is entering a 50-meter section it connects to the ERS. The system then receives all shared data that is enabled by the vehicle, like for example battery status. According to Evias, there is an integrated system to measure energy consumption on the ERS, both per substation and per vehicle. This system was tested on the public test track when it was in operation. However, in eRoadArlanda the energy measurement of the substation was performed by Vattenfall with their conventional system. In addition to this, Evias did add several energy measurement units to measure how the energy was distributed between the substation and the truck (through the rail section) as well as additional units in the vehicle that then sent back the data with GSM. In a commercial system, so many units would not be required. Evias is currently waiting on more specific information regarding in what interface the energy should be measured and based on this they can decide on how the system should be designed in the end. Vehicle identification was also tested in eRoadArlanda, both once the vehicle connects to the ERS and repetitively per 50-meter section. However, the system can currently only manage one vehicle per time. Evias have developed a solution to manage this but need more specific requirements to decide on how to define the system. In parallel, Elways is currently investigating how to add more equipment into the rails rather than relying on external vehicle data or to have to add additional equipment on the vehicles. For billing and payment solutions, Elways have begun to develop an open API (Application Programming Interface) to support sharing relevant information from their system to relevant external actors. This is currently in an early development stage and have not been tested yet. As both energy measurement and vehicle identification have been tested on eRoadArlanda the systems could be seen to have reached TRL 6. However, the fact that the system for energy measurement is oversized and far from its commercial application, the subsystem could be seen to be more focused on testing components, hence limiting it to TRL 5. Both subsystems seem to still be under reconstruction/redesign to make them rely less on external vehicle data and the need for additional equipment on the vehicles. If the systems will be redesigned significantly in the future this will result in lowering the TRL of the subsystem. The magnitude of change is hard to assess but could be major. As no proof of concept have been identified for the commercial design of energy measurement, the subsystem is limited to TRL 2. For vehicle identification a system solution has been developed to

	manage several vehicles, but still needs to be validated, hence corresponding to TRL 3. The open API to support payment and billing solutions have not been tested yet and is currently in an early development phase. As Elways are currently working on critical functions for sharing the data and to formulize the concept, the subsystem has not yet reached TRL 3, hence limiting it to TRL 2.
Electreon	Both vehicle identification and energy measurement are built-in to the Electreon system. Energy measurement is done both in the road and on the vehicles at the public test track, Smartroad Gotland. Today, the subsystem is measuring this data from point to point, but Electreon is currently developing a system to move all this data into a cloud-solution for easier access and allocation of data. There is still a need to make the energy measurement unit more accurate to fulfil the same requirements as for a traditional energy measurement unit. Even though the system for energy measurement has been tested on Smartroad Gotland, the need to make the system more accurate limits the subsystem to TRL 6 today. Vehicle identification, which has also been tested, seems to work sufficiently for its application, hence it has reached TRL 7. Enabling shared data in a cloud-solution is the first step towards a billing and payment solution according to Electreon. As their system already collects the data for identification and energy consumption per vehicle, Electreon do not see the process of providing an external supplier with such data as a huge challenge. Electreon is currently certifying itself in payment solutions in Germany, no similar activity has been noticed for Sweden. Electreon is currently focusing on developing a cloud-solution to share the relevant data in order to create billing solutions (probably provided by external actor). This solution will be implemented in the test track currently under construction in Italy, and Smartroad Gotland will later be updated to the same level. However, as the system is in a very early stage and no or limited validation along test track have been carried out, the subsystem is currently limited to TRL 4.

Subsystem - Vehicles

Subsystem	**Vehicles**
Siemens eHighway	For the Siemens eHighway technology standard production vehicles can be used, with the pantograph tower installed on top. Siemens is focused on trucks and do not at this moment pursue proving and adapting buses for the ERS. Same components, e.g. infrastructure and pantograph, would however be possible to use for this application as well. Pantographs have been implemented on various truck types and by different project partners, covering more than a total of 50.000 electrified km driven on eHighways according to Siemens. As a number of public test tracks have been in operation over several years, trucks have been tested in full highway speed extensively. The test tracks are however relatively limited both in terms of number of vehicles and km ERS

	compared with a full-scale system, hence the system can be seen to have reached TRL 8.
Elonroad	All vehicles with four wheels are expected be able to use Elonroad's ERS. Currently a bus with a power transfer of maximum 200 kW has been tested on the public test track in Lund. Some tests (propulsion and dynamic charging) have also been done with a converted Nissan Leaf (passenger car) with a 15-kW receiver. A Volkswagen E-Crafter (transport car, 3.5 ton) has been tested with propulsion, but not on-board charging on the public test track. In lack of charging, Elonroad have instead connected a heating fan to the vehicle to illustrate the amount of energy that charging would absorb. Currently they lack test vehicles in terms of a heavy truck, but this is something they want to test in the future as soon as they have access to such vehicle. For a truck, the plan is to make the receiver longer (from current 2 meter to 3 meter) so that it can connect to two segments/switches. This application should not differ from other vehicle types, e.g. a bus. For the application of city buses, the bus in Lund have been tested in an operational speed of up to 60 km/h, corresponding to TRL 7. The passenger car is planned to be tested in speeds up to 70 km/h, but as the speed limit of the road is 40 km/h, Elonroad need permission for such tests. It could be questioned if the typical operational speed of a passenger car is fulfilled, and the conclusion is that more extensive testing is needed, especially in a higher speed range, to fully represent TRL 7. As the tests with the transport car do not include dynamic charging, this vehicle application is currently limited to TRL 6. No truck has yet been tested.
Evias	Elways technology are designed to support dynamic charging for all four-wheeled vehicles. At eRoadArlanda, a truck has been tested extensively at speeds up to 80 km/h, which means that the technology in that application area corresponds to TRL 7. From a technical perspective, the energy provided (kW) are probably not a limiting factor for reaching higher speeds, however several aspects such as how the receiver will perform in higher speeds in terms of losses, wear etc. are still unknown. As a truck has been tested in speeds up to 80 km/h, which is close to the highest operational speeds, the subsystem has reached TRL 7. A passenger car has also been tested at the public test track, but only mechanically not by charging the battery, hence limiting it to TRL 6. On the non-public test track, a passenger car has been tested in speeds up to 120 km/h. Tests in high speeds are primarily limited by the speed limit on the road and the condition of the road, rather than technical restrictions. Both a bus and a van has been constructed but not yet produced, hence no test has been made with such vehicles.
Electreon	The principal design of the vehicle receiver does not differ between different vehicle applications. However, the number of receivers per vehicle varies depending on how much transferred power that is required. The initial receiver is dimensioned for a passenger car, which is then scaled up by adding additional units for the entire range from passenger cars to very heavy trucks. A truck (125 kW) has been in operation on the public road track at Gotland since December 2020 and been run in speeds up to 80 km/h. However, according to the Swedish Transport Administration's functional requirements

	the power need to be increased to 175 kW. This means that the system does not work sufficiently for the truck application, hence limiting the subsystem to TRL 6. Based on WSP's knowledge, there are no corresponding requirements for buses and therefore the application for buses can be seen to work sufficiently for its application in speeds up to 50 km/h, hence reaching TRL 7. Electreon have done several installations in collaboration with vehicle suppliers on their test tracks (not public road), both for passenger car and van, hence arguably corresponding to TRL 6.

Within the project, WSP have also asked the ERS-suppliers to provide their own technology assessment regarding TRL for respectively subsystem. The results are illustrated in Table 3.

Table 3. ERS-suppliers' estimate on the TRL of their subsystems. All inputs were provided during the period of Nov-Dec 2021, except from Electreon who gave their input later by the end of Sep 2022 (due to no initial reply).

Supplier **Subsystem**		**Siemens EHighway**	**Elonroad (in road)**	**Evias**		**Electreon**
				200kW	**800kW**	
Electricity Supply		TRL 9	TRL 7	TRL 8	TRL 6	TRL 8
Road		TRL 9	TRL 7	TRL 8	TRL 8	TRL 8
Power Transfer to Vehicle	< 60 km/h	TRL 8	TRL 7	TRL 8	TRL 6	TRL 8
	> 60 km/h	TRL 8	TRL 7	TRL 8	TRL 6	TRL 8
Daily Road Operation	Energy Measurement	TRL 8	TRL 7	TRL 8	TRL 8	TRL 7
	Vehicle Identification	TRL 7	TRL 7	TRL 8	TRL 8	TRL 9
	Billing and Payment Solutions	TRL 7	TRL 7	TRL 8	TRL 8	TRL 7
Vehicles	Truck	TRL 8	TRL 7	TRL 8	TRL 8	TRL 8
	Bus	Not pursued at this moment	TRL 7	TRL 8 TRL 6	TRL 8 TRL 4	TRL 8
	Van	N/A	TRL 7	TRL 8 TRL 6	TRL 8 TRL 4	TRL 7
	Car	N/A	TRL 7	TRL 6	TRL 4	TRL 8

By comparing Table 2 (WSP's assessment) and Table 3 (ERS suppliers' assessment), it can be concluded that the ERS suppliers in general estimates the TRL for each of their subsystems to be greater than what WSP does. It is difficult to pinpoint the exact reason behind this difference, as it could depend on several factors. However, the fact that the suppliers have much more information about their technical systems and the corresponding status in their current development than WSP could be one contributing part. Also, an underlying bias of the supplier to perform high in terms of TRL could impact the subjective criteria in the assessment extensively, resulting in higher values.

Evaluation of technology maturity

For this part, WSP has been given (by the client) a few predetermined work packages (WP) covering various subjects. Each work package has had an assigned overall specific subject, where experts from WSP then, within that given subject, have identified a limited number of criteria/aspects that are crucial and of high importance for evaluating the maturity of implementing ERS into the road system. The work packages are given as:

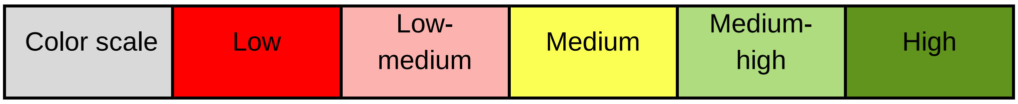
- 2.1 Potential for larger implementation
- 2.2 Operation & Maintenance
- 2.3 Traffic Management Systems
- 2.4 LCA / LCC
- 2.5 Interoperability (*not included in this part, see separate chapter XX WP 3.2 + 2.5*)
- 2.6 Energy measurement and billing (*not included in this part*)
- WP Non-ERS (*partly included in this part, partly in separate chapter WP 5*)

For WP 2.1-2.4, each work package has identified key criteria/aspects that then have been assessed and converted into an overall matrix, see Table 4. Depending on WP, the matrix assesses the degree of its potential (WP 2.1), additional complexity (WP 2.2 and 2.3), or current state of knowledge (WP 2.4), that it entails for a specific criterion/aspect for respectively ERS-technology. For more details and in-depth explanation of each criterion/aspect, see the chapter for the respective work package.

Note that this section and table are not intended to form a basis for which technology that is most suitable to choose nor to cover every relevant aspect to consider in such a decision, but rather to describe the potential and complexity of each individual technology (not in relation to each other) for a given number of criteria. Also note that the assessment was carried out in spring 2021 and finalized by December 2021. New information and data that have emerged after this have not been included in the evaluation below.

The degree of potential (relevant for WP 2.1) and current state of knowledge (relevant for WP 2.4) have then been graded according to the color scale in

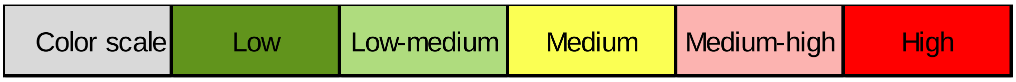
Figure 3.



Color scale	Low	Low-medium	Medium	Medium-high	High

Figure 3. Color scale of WP 2.1.

The degree of additional complexity (relevant for WP 2.2 and 2.3) has then been graded according to the reversed color scale .



Color scale	Low	Low-medium	Medium	Medium-high	High

Figure 4. Color scale of WP 2.2-2.3.

Table 4. Overall matrix covering a selection of criteria/aspects from WP 2.1-2.4 and partly WP 5, graded by the degree of additional complexity or potential it entails. BEV = Battery Electric Vehicle and H2 = hydrogen fueled vehicle.

	Technology Criteria/Aspect		Siemens eHighway	Elonroad	Evias	Electreon	BEV	H2
WP 2.1 – Larger implementation	Short lead time for deployment		Low	Low	Low	Low	Medium-high	Low-medium
	Potential for vehicle market ramp-up till 2030		Low-medium	Low-medium	Low-medium	Low-medium	High	Low
	Potential for infrastructure roll-out till 2030		Low-medium	Low-medium	Low-medium	Low-medium	High	Low-medium
	Not dependent on a single provider		Low	Low	Low	Low	High	Medium
	Potential for decarbonation of different truck operations	Local	Low	Low-Medium	Low	Medium	High	Low
		Regional	Medium-high	Medium-high	Medium-high	Medium-high	Medium-high	Medium
		Long-distance	High	High	High	High	Medium	High
	Potential for decarbonation of Different vehicle operations	*Trucks*	High	High	High	High	Medium-high	High
		Bus	Medium-high	High	Medium-high	High	High	Low-medium
		Vans	N/A	Low-medium	Low-medium	Low-medium	High	Low
		Cars	N/A	Low-medium	Low-medium	Low-medium	High	Low
	Potential to implement on public roads	*European roads*	High	High	High	High	High	High
		Highways	High	High	High	High	High	High
	Potential to implement on Municipal roads	*Urban area*	Low	Medium	Low	Medium	High	Medium
		Not urban area	Low	Medium	Medium	High	High	Medium
WP 2.2 – Operation & maintenance	Impact on road body / facility		Low	Medium	Medium-high	Medium-high	N/A	N/A
	Impact on the operation and maintenance of the road		Medium	Medium	Medium	Low-medium	N/A	N/A
	Costs for operation and maintenance		Medium	Medium-high	Medium-high	Low	N/A	N/A
	Maintenance costs and system failure caused by vehicle accident		Medium-high	Medium	Low-medium	Low	N/A	N/A
	Risk assessment regarding third party activity in, or next to, the (extended) road area (farming, excavation, installation of utilities, etc.)		High	Medium	Medium	Medium	N/A	N/A

	Need and extent of service roads and diversion routes when road or ERS are off during operation and maintenance	Medium-high	Medium	Medium	Low-medium	N/A	N/A
WP 2.3 – Traffic Management Systems	Need to monitor the ERS if a vehicle accident occurs	Medium-high	Medium	Medium	Low-medium	N/A	N/A
	Need to redirect traffic during planned or unplanned maintenance/repair	High	High	High	Medium	N/A	N/A
	Need to enable real-time data from the ERS-infrastructure and the ERS-vehicles	High	High	High	High	N/A	N/A
	Additional need to enable real-time data from non-ERS vehicles	Medium	Medium	Medium	Medium	N/A	N/A
	Need to enable communication between the vehicles and the traffic management system to share real-time data of the traffic on road section of the ERS	High	High	High	High	N/A	N/A
WP 2.4 – LCC/LCA	Environmental impact from construction and maintenance of ERS infrastructure	Low-medium	Not included	Low	Not included	Not included	Not included
	Investment costs for ERS at commercial scale	Medium-high		Medium-high			
	Additional maintenance cost for the system	Medium		Low-medium			
	Service life for system/components, and replacement strategy	Low-medium		Low-medium			

Regarding larger implementation (WP 2.1), it can be concluded that Battery Electric Vehicles (BEV) are the technology with most green fields, hence possess the highest potential for reducing CO_2 emissions. This is also in line with the discussion that took place during the first CollERS workshop for technology assessment held in November 2021 with representatives from German and Sweden. The main reason for this is that the technology seems to have the shortest lead time for deployment and has the potential to contribute to all vehicle's segments and in all truck operations, although it is still uncertain to what degree for the long-distance segment. However, the fact that the exercises on the technology workshop held in November were predefined by the Germans to be focused on the ramp-up and roll-out of the technologies until 2030, the short time frame could be to the advantage of BEV and to the disadvantage of ERS and H2.

From WP 2.2, Operation and maintenance, it can be concluded that the degree of additional complexity seems to differ both within respectively criteria/aspect when all technologies are compared, as well as within a single technology when criteria/aspects are compared to each other. In general terms, Electreon seems to pose slightly less additional complexity, mainly since the ERS-technology is not placed above or on the road surface. At the other end of the spectrum, it seems that Siemens eHighway is the technology that has the highest additional complexity, mainly as vehicle accidents could become quite critical for the system, and in such cases, the need for third party activity in the road area and most likely diversion routes could be needed. The conductive technologies (Elonroad and Evias) do only differ slightly in some of the aspects.

It can be concluded that all ERS-technologies impose a high degree of additional complexity for the Traffic management systems (WP 2.3). The sole criteria in this assessment that is deemed to somehow differ, is the need to monitor the ERS if a vehicle accident occurs. For this, the Siemens eHighway technology poses the highest complexity as vehicle accidents are deemed to be more critical, and hence there is a continuing need to monitor the facility, for example in a case where the overhead line would drop down in the road area. For the Elonroad and Evias technology, the probability of a similar situation to appear is considered lower. As Electreon does not have any technology above or on the road surface, this will not be an issue.

For the LCC and LCA analysis, the comparison has been focused on solely the Siemens eHighway and Evias technology. It can be concluded that the current state of knowledge for all aspects is deemed to be quite low, except for investment costs for ERS at commercial scale. When comparing the two technologies, there seems to be slightly more available data for the Siemens eHighway than for Evias, which is mainly because the overhead catenary system is based on an old conventional technology and hence some data can be extracted from other applications areas, such as buses, trams, and railways.

WP 2.1b Potential for large scale roll out

For WP 2.1, the assessment is mainly based on produced knowledge and information within the project, both from WSP internal WP’s and from the discussions during the technology assessment workshop that was carried out on 2021-11-09 between experts from Sweden and Germany. As a complement to this, WSP also has previous relevant experiences within the field that have been utilized for the assessment.

As one out of several topics discussed in the technology assessment workshop, one outcome was that ERS and H2, in general, seem to be characterized by longer lead time for deployment and for market ramp-up than corresponding BEVs. ERS is also, in general, to a higher extent dependent on a single provider than alternative non-ERS technologies.

On a generic overall level, ERS has its highest potential to decarbonate the two vehicle segments trucks and buses. Geographically this would be mainly on national roads (European roads and highways) and for long-distance operations. There are however some ERS-technologies (for example Electreon and to some extent Elonroad and Evias) that also potentially could be an alternative for municipal roads (in or outside urban areas).

BEV on the other side is concluded to have a high potential for all vehicle segments (trucks, buses, vans, and cars), although there could be some limitations for specific transport operations that are less feasible for trucks and buses. This could, at least in short to medium term, be the transportation of heavier goods in regional or long-distance routes.

The potential for H2 is in many cases similar to the one for ERS, with some exceptions. As there is already some, but very limited, infrastructure available, the lead time for deployment for H2 could become a bit shorter than for ERS, at least in limited applications. The ramp-up of H2-compatible vehicles is however deemed to be lower than for electrified vehicles (BEV and ERS vehicles). As H2 vehicles are not geographically limited to a specific road but rather limited to the availability of fueling stations, the technology has a theoretical potential to decarbonate traffic flows on both national roads and municipal roads. However, to get value and utilize the longer range that H2-vehicles possess compared to a BEV, its potential for local applications is deemed to be quite limited. Hence, H2 will most likely be mainly present in regional or long-distance operations. The highest potential will however most likely be long-distance operations that have a large energy demand and where batteries thus might not be a feasible alternative (Elektrifieringskomissionen, 2021).

WP 2.2 Operation and maintenance

ERS constitutes an additional system to be integrated into the road facility, hence there will most likely be an impact on the operation and maintenance of the road. As it might arise issues regarding these aspects, it is important for the road operator to consider these when deploying ERS. In this chapter, the following aspects are covered:

- Impact on road / facility
- Impact on the operation and maintenance of the road
- Cost for operation and maintenance
- Maintenance costs and system failure caused by vehicle accident
- Risk assessment regarding third-party activity in, or next to, the (extended) road area (farming, excavation, installation of utilities, etc.)
- Need and extent of service roads and diversion routes when road or ERS are off during operation and maintenance

Note that the six areas above are corresponding to the aspects covered and graded in Table 4 in the previous chapter. Hence, this chapter should be read as a more detailed explanation of the underlying knowledge and reasoning behind the grading in the table. Also note that the system perspective for the responsible party of the conventional operation and maintenance of national roads (the Swedish Transport Administration in this context) has not been included in the assignment and hence this chapter. This means that, for example, questions such as how a future possible government assignment regarding operation and maintenance of ERS would affect the Swedish Transport Administration's organization and current operations have not been addressed in this chapter.

The basis for WP 2.2 has been to analyse the following previous reports covering ERS impact on roads facility and operating and maintenance perspectives:

- COLLERS - Swedish-German research collaboration on Electric Road Systems 2020-09-18
- RISE - Digital Systems Electromobility, Report 2021:23) (RISE, 2021))
- ERS Impact on Road Construction, Maintenance and Operations (Nordin, McGarvey, & Ghafoori, VTI rapport 1052A: Electric Road Systems. Impact on Road Construction, Maintenance and Operations, 2020)
- Vägunderhåll och kostnader för olika typer av Elvägar TRV 2020/77969 (eng: *Road maintenance and costs for different ERS TRV 2020/77969*) (Trafikverket, 2020)
- Analysera förutsättningar och planera för utbyggnad av elvägar TRV 2020/113361 (eng: *Analyse conditions and plan for the extension of ERS TRV 2020/113361*) (Trafikverket, 2021)

Other studied documents and performed interviews:

- eRoad Arlanda L1.6 ”Slutrapport - sammanställning av Kunskapsunderlag” (från 2019-09-03) (eRoad Arlanda L 1.6 "Final Report - Summary of Knowledge Base, 2019)
- Regler för statliga elvägar SOU 2021:73 (eng: *Regulations for public ERS SOU 2021:73*) (Elvägsutredningen, 2021)
- Performed interviews with suppliers representing Elonroad, Evias/Elways, Electreon and Siemens (Elonroad, Evias/Elways, Electreon, & Siemens)

Impact on road / facility

Different concepts and techniques impact on roads facility

The different concepts outlined in the studied reports will have an impact on the road facility. Some concepts will impact the road’s structural integrity itself while other concepts will require new structures along the facility that will have to be protected by installing additional equipment. Concepts that require installation in the pavement structure will increase the risk of failure due to cracking and/or deformation while concepts installed beside the facility (i.e. overhead catenary lines) will not affect the pavement itself but require additional maintenance.

Catenary overhead power line (concept) with Siemens e-Highway (technique)

The catenary technology will not have a direct impact on the road structure. Although there will be a need for a lot of infrastructures such as support masts, concrete foundations, and longitudinal guardrails. This means that side-verge areas, drainage ditches with culverts and cable-infrastructure will be affected. The overhead conductive solution will require excavations or piling in the side-verge area which can influence the road structure and may result in different kinds of damage. Geotechnical investigations will be needed before installation in order to assess the magnitude of reinforcements needed to keep the settlements of the catenary system to a minimum.

Conductive in-road rail (concept) with Evias rail (technique)

For the installation of conductive in-road rail technology steel rail segments with the length of 12 m per each segment must be milled into the road structure. Four segments are assembled to become one rail section. The rail section is then connected to an input rail of 3 m in length with transverse connecting cables connecting to switching boxes and power supply cables in the verge side area. Important is the sealing of the vertical joint between the ERS unit and the surrounding structure to prevent water ingress. Later versions of the rail segments have evolved to be in concrete with electrical rail inside (Evias at eRoadArlanda). Investigation of roads existing structural layers should be made before any milling, excavations, and installation to detect unknown conditions.

Conductive on-road rail (concept) with Elonroad rail (technique)

Elonroad has developed two types of on-road rail techniques. For municipally owned roads there is a rail installed on top of the asphalt and due to request by Swedish Transport Administration, there is also a variant more like the in-road rail concept where Elonroad has the most superficial design with only 6 cm milling.

The on-road rail concept consists of a rail laid on top of the asphalt. With the Elonroad technique, the rail is mounted in 10 m long sections consisting of 1-metre-long segments connected one after the other making a single rail. Rail is attached by mounting plates that are glued or bolted on to the road surface. Power supply to the rail is required every kilometre which means a transverse excavation track for the power supply cables. Power supply station can be placed outside roads side-area and therefore will no guardrails be needed. Investigation of roads existing structural layers should be made before any milling, excavations, and installation to detect unknown conditions

Inductive embedded coils (concept) with Electreon (technique)

Inductive technologies are completely embedded within the road structure with no visible signs of an ERS, as the coils are hidden beneath the surface. Substations can be placed outside roadside area with approx. 1 km longitudal spacing. If management units can be placed beneath ground surface, there will be no need for side barriers. Investigation of roads existing structural layers should be made before any milling, excavations, and installation to detect unknown conditions. Inductive coils with connecting cables embedded within the road structure may cause weak points on the road surface.

Inductive techniques with embedded coils may also cause conductive heating of the surrounding road materials which may affect the characteristics of the structural layers within the road structure. This could in turn lead to decreased strength, skid resistance, waterproofing and surface profile.

Three different installation techniques for inductive concept are mentioned:

1. Trench-based construction
2. Micro-trench-based construction
3. Full lane width construction

Impact on the operation and maintenance of the road

Different concepts and techniques impact on operation and maintenance

The additional need for operation and maintenance both for the ERS and the road structure as well as the side-verge area varies depending on ERS technique but will in any case tend to lead to increased costs once the ERS is integrated in the facility. An increased amount of maintenance operations and repairs can be expected for roads with ERS installed. One of the previous reports, Vägunderhåll och kostnader för olika typer av Elvägar TRV 2020/77969, included a cost comparison for the different concepts and techniques studied due to operation and maintenance.

It should be noted that the current road network’s reliability is a product of its simplicity. The materials and techniques for construction and maintenance have not changed much over the years except for machinery replacing manual procedures. By introducing additional components in the structure to support the investigated systems the complexity of the construction will scale up and most likely add vulnerabilities to the superstructure.

Introducing these vulnerabilities will affect the service life and make the results from maintenance more susceptible to variability (where the contractor’s skill and commitment will play a large role). These vulnerabilities include, but are not limited to:

- Joints between materials
    - Asphalt concrete
    - Concrete
    - Steel
    - Plastic/rubber tubing
- Uneven bearing capacity across the section of the road
- Covered drainage systems (pipes and structures)
- Installed equipment prone to uneven settlement (poles, guardrails)

Catenary overhead power line (concept) with Siemens e-Highway (technique)

Maintenance and repairs can be expected on the ERS-equipment itself such as pantograph collector strips and contact cables as well as additional maintenance work at roads side verge area.

The required installation of supporting masts and guardrails will make all regular maintenance of the safety zone (including side slopes and ditches) more time consuming. The guardrail itself will also require maintenance at regular intervals as well as immediate repairs if they get damaged by vehicles going off course or by maintenance equipment.

Because of the height limitation of catenary overhead cables, the pavement maintenance will be more complicated and time-consuming. Feeder/shuttle buggy instead of asphalt lorry has to be used to support the asphalt pavers.

The overhead cables will also complicate maintenance operations by restricting the movement of lifting arms. Lifting arms could hit overhead cables and are used during cleaning of rest areas and side verge cutting.

Conductive in-road rail (concept) with Evias rail (technique)

The large number of construction joints and the introduction of new materials make this concept susceptible to damage. It will be very important to keep bonds and joints intact and systematic inspections of these will be vital.

In general, drainage is one of the most important road maintenance operations. Water on or in the road may cause damage to the road both on the surface and in the construction. With a conductive rail installed in the road structure, the issue will be to provide water ingress both in the joints between different materials and to ensure drainage of the structure in its whole including the water to run off the surface. Irregularities caused by the installed ERS can make this more difficult.

An additional maintenance activity will also be to frequently rinse the rail to remove dirt and particles that get stuck in there. Also, winter maintenance will be extended with the issue to keep the rails free from packed snow and ice formation, as the power transferring pick-up unit will otherwise force ice or snow out of the rails and cause a safety risk. Methods for de-icing have to be evaluated. By adding a special cleaning plow to the pick-up unit, rails can to a high degree be kept free by the daily operating vehicles (Evias). In this case, the cleansing gets better the more vehicles that pass.

This concept will increase the need for maintenance and repairs. First, by maintaining the ERS itself. Secondly, by increasing the maintenance required to preserve the service life of the superstructure.

Conductive on-road rail (concept) with Elonroad rail (technique)

For the technique that uses a rail installed on top of the asphalt via mounting plates, the rails are glued or bolted on the road surface. Also, transverse power supply cables need to be excavated into the road structure. This will affect the durability of the road structure similar to both the in-road rail concept and the inductive concept. When the pavement maintenance must be performed, the on-road rail must probably first be removed and thereafter be placed back again.

A need for additional winter maintenance will be required. Other types of snow ploughs than the usual ones need to be used and evaluated. For this, a special snow plough for the on-road rail will be provided by Elonroad, but this still needs to be integrated with existing maintenance fleet, including learning new operation practices etc. The most common and viable de-icing agent used in Sweden is salt and this will have a corrosive impact to the rails. Hence, other types of de-icing agents have to be evaluated for the ERS.

Inductive embedded coils (concept) with Electreon (technique)

It may seem that with an inductive concept, daily maintenance will not be significantly affected because the ERS is completely embedded within the road structure. There will however still be an issue to reduce the number of transverse utility cuts and to handle the unevenness caused by these. Also, this concept includes construction joints and material changes which may cause irregularity in the structure and in its extension water intrusion, crackings and unevenness for the maintenance contractor to manage. For evaluating long-term effects, full-scale tests will need to be studied. Excavated management units and supporting cables can also affect maintenance in the roads side area such as example drainage works. It will also be extra important to keep the roads clear from snow and ice to prevent a reduced function for the inductive power transfer.

Costs for operation and maintenance

With an ERS implemented in roads facility, there will be additional maintenance costs, both for the ERS itself and also for road maintenance. Some risks for operation and maintenance have been identified once an ERS is implemented in the road’s facility. The risks and costs that can arise regarding them will vary depending on the concept/technique while some risks are more general for all technologies. The current risk level also depends on the degree to which different ERS have been tested, which over time could reduce the risks continuously as experiences and practices of different critical aspects increase.

Since ERS constitutes a longitudinal physical installation, this can lead to increased linear driving patterns and thus some increased rutting in the roadway. This means some increased track deformation in the road surface/wear of asphalt layers.

As described under *Different concepts and techniques impact on operation and maintenance* there will be a risk of impact to the roads body and increased costs associated with an ERS installation. This will affect the maintenance of the road and perhaps also the road’s service life. Long term effects on road body and structure with an ERS installed are yet to be studied as some aspects are not expected to occur during the limited period of time that current ERS-demonstrators and test sites are in operation.

It is likely that risk analyses will be made by ERS-suppliers before any installation and operation (Electreon at test site Smart Road Gotland and Evias at eRoadArland are mentioned).

Adaptation of maintenance machines and equipment for roads with ERS installed will increase the costs for such vehicles and the use of them in the short term. When these are more established in the market the cost will probably not differ much from more common equipment. For example, the development cost should initially be spread over just a few units. When ERS are deployed, the manufacturer has provided more produced units to the different maintenance organizations. In general maintenance methods and machines differ between regions and therefore also the costs. The use of more adapted equipment or vehicles can, therefore, initially be a cost driver, but also be a way to reduce the continuous extra costs as the maintenance is performed.

The use of stainless steel in ERS-components (as in Evias in-road rails) would make it possible to use salt as de-icing agent for roads winter maintenance. Also, the use of heating cables can reduce risk for system failure.

Road resurfacing usually occurs every 10 years. Due to designed service life and the actual wear of an ERS, different components will have to be replaced around the same time. It should therefore be possible to coordinate planned maintenance on both road and ERS installation. This will be cost effective and will also minimize disruption for regular traffic.

There will be a need for a trade-off between investment costs and maintenance costs. This also applies to the possibility of oversizing other system components. As an example, rail-constructions more resistant to solar curves are available but will increase investment costs.

To a certain extent, it should be possible for the same personnel to perform maintenance on both subsystems road and ERS installation as they will be integrated with each other. This presupposes basic electrical safety training for the personnel with probably an extended part for the personnel who specifically work with electrical components in the system according to applicable electrical safety regulations.

As the different techniques still are in the development phase and future projects will have their own unique conditions, it is still difficult to specify costs in detail. One of the previous reports, Vägunderhåll och kostnader för olika typer av Elvägar TRV 2020/77969, included a cost comparison for the different concepts regarding operation and maintenance. A future need to study the difference in costs regarding installation and additional claim for road area has been identified. The need and extent of access to substations and management units may vary between concepts and road categories. This can for example be differences in the amount of service roads and claim for extra road area. As more kilometres of ERS are being built, e.g. the future procurement of a regional pilot in Sweden, a better basis for a comparison will be made available.

Maintenance costs and system failure caused by vehicle accident

If a vehicle accident occurs, the ERS can be affected or even damaged. This would mainly apply to ERS installations with external components such as catenary poles and contact cables. For other types of ERS, the use of control cabinets in roads safety zone involves a cost for guardrails.

In the event of an accident, the emergency services must understand the system and be able to ground the electric parts of the system. Moreover, the ERS would most likely in such a situation need to be disconnected for a period in order to do inspections and necessary repairs before the system gets its functionality back again. Regarding this, it is likely that there can be additional costs for not only ERS operators and ERS subsystems but also for stakeholders such as transport operators and transported goods owners regarding delays. Road safety measures should be considered depending on road category and current conditions. There is probably no case yet to study for the task, but some assessment can be made which has been derived below.

Catenary overhead power line (concept) with Siemens e-Highway (technique)

Exposed parts in this system are primarily the overhead power lines and the catenary poles. Roadside safety barriers will reduce some of the risks for damages, but there are no guardrails designed to withstand 60-ton trucks. This could affect the outcome of an accident in a system with roadside installations.

Conductive in-road rail (concept) with Evias rail (technique)

There is probably a very small risk of system damage caused by a vehicle accident. The issue will instead be to ensure rails level of friction corresponding with connecting road surface to prevent vehicles slippery accidents. With Evias technique the issue is solved with a rail outer box of concrete with a top of asphalt concrete with a similar friction level as surrounding asphalt. Electric components and power transferring will then be inside the box.

Conductive on-road rail (concept) with Elonroad rail (technique)

The on-road rail can be assumed to be exposed to failure or damage in case of a vehicle accident. The action will then be to replace damaged rail segments. For the milled version of the rail, conditions will be similar to the Evias technique.

Inductive embedded coils (concept) with Electreon (technique)

As long as there is no ERS infrastructure above ground or on the road surface with this concept there will probably be a very small, or no risk at all for system damage. If management units are placed above ground, roadside barriers will be required, and the impact of those will be similar to corresponding technologies (e.g. Siemens).

Risk assessment regarding third party activity

Some risks regarding third-party activity next to the road area where there is an implemented ERS have been identified. Primarily all hidden/excavated high-voltage ERS-components and connection cables may pose a risk for third-party activities which involve any form of agriculture, forestry, and excavation. It will be important to document and communicate the location of such installations. Conversely, there is also the risk of ERS-installation being damaged by such activities.

Specific for the catenary system will be to ensure a corridor free from trees and other hazards. The risk of falling trees can also be expected to increase due to climate change.

Service roads and diversion routes during operation and maintenance

The need and extent of service roads can be expected to increase with an ERS integrated, primarily for access to ERS-installations next to the road. In most cases, both road and ERS maintenance would still be possible to perform by using TMA-trucks and according to the Transport administrations APV regulations.

It should be considered that even if it´s possible to perform maintenance on, for example, catenary poles and power supply stations from roadside, still parallel service roads will minimize disruption to traffic and improve working environment but will also increase costs and in some cases the claim of extra road area.

During the installation and maintenance of an ERS, the road can be expected to be, at least partly, closed for regular traffic for a period and therefore also diversion routes have to be planned and used. Since major part of traffic load are using the slow lane and overtaking lane might not be dimensioned for such load, there can be an issue with traffic diversion from slow lane to overtaking lane during ERS installation. Roadholder has to take into account during the planning phase how to handle regular traffic depending on the time required for the performance of installation and maintenance of ERS. Swedish Transport Administration has diversion plans for state roads and a routine for updating and identification of diversion routes (TDOK 2020:0078) which will be useful during the planning (Trafikverket, 2020).

Both installation and maintenance with, for example, replacement of an in-road rail installation means that the road’s slow lane and roadside will be disposed as a work area under a period with a limited possibility for regular traffic.

WP 2.3 Traffic management systems

Today, the grade of monitoring on state roads differs depending on the type of road (e.g. high traffic roads, complex road facilities). In general, the current monitoring system can provide information to drivers via external sources to the driver, but by introducing ERS, the complexity of the system will increase the need for additional monitoring and greater exchange of information to support a safer environment for rescue missions. Hence, the Swedish Transport Administration will probably have to expand the current system, in terms of adding new functionalities, so that it can manage the complexity of the new systems, by for example the use of traffic monitoring, information flows between cars, charging technology and live parts. Another alternative could be to build a completely new traffic management system for the ERS with trained operators that monitor the vehicles that utilize the ERS and who can turn off the affected sections and redirect vehicles if needed. Such alternative would however most likely become quite costly and resource inefficient and would still have to communicate with the current traffic management system and its traffic managers.

Current traffic management system

The Swedish Transport Administration have a well-defined process of how to monitor and manage traffic deviations in their traffic management system. The system consists of the four different levels: Field – Local – Central – NTS, where NTS stands for National traffic management support ("Nationellt trafikledningsstöd"). See Figure 5 below.

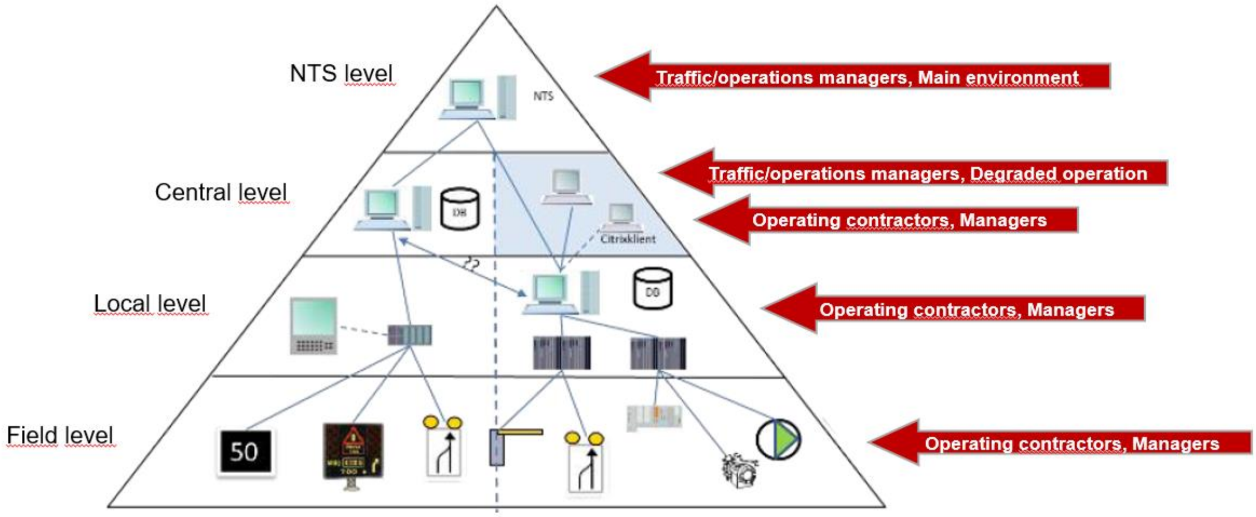


Figure 5. Overall system structure for the traffic management system at the Swedish Transport Administration.

Most of the traffic and operations managers at the Swedish Transport Administration are located and working in the top level, the NTS system. Traffic and operations managers are hence monitoring all the facilities nationally by the support of the lower levels in the pyramid in Figure 5. If a failure, accident or similar is identified in the system, this is reported up to the NTS system and then traffic and operations managers have pre-defined action plans for how the situation should be handled which they then spread down to affected areas of the pyramid to manage the situation. The communication for this could both be an alarm, phone call etc. Depending on the reported case, actions such as instructions to shut down a field or, for example, call the rescue center, can be actions that are fed down the pyramid. If something needs to be fixed, a work order will be sent out to the affected operating contractor who will go out and fix the fault. This could be on either field-, local- or central level.

On the central level, there are some additional operation managers or operation technicians working. They are primarily working in the systems at the central level which covers the entire region, which the lower levels (local/field) in the pyramid are feeding back to.

At the local level, local control equipment monitors and controls various monitoring and road equipment located at the field level. Thus, all monitoring and road equipment is primarily located at the field level, including cameras, traffic signals, signs etc.

On a rather overall level, if an ERS would be added, the ERS equipment would be located at the field level, then there would be a need to add some additional local process to control this at the Local level. On the central level, there would most likely be a need to add an overarching electric operation management system that monitors the electric road components which then are communicating up to the traffic managers at the NTS level.

Monitoring of ERS

All monitoring in the current and future system will primarily be done with cameras that utilize image analysis and operators that monitor the signs, along with cameras. To detect for example stationary vehicles, there are however other tools available, for example radar. This is a commonly used tool today, in particular on road sections where cameras are not available.

The control and monitoring of electric power are done both in the ERS built-in technology (field level) and probably by integrating it into the current traffic management system process (mainly local-, central- and NTS level) at the Swedish Transport Administration. For the upcoming ERS-pilot, the Swedish Transport Administration is working with the assumption that it must be possible to monitor all vehicles on the ERS-section, no matter if they are connected to the electric road or not, hence both radar and cameras will be utilized. However, it is not certain that it needs to remain that way on longer terms once ERS is deployed in larger scale. The need for camera surveillance and monitoring of powered segments in the ERS will take place gradually with the expansion of the electric road. All ERS techniques are equipped with an internal system to monitor connected vehicles to the electric road, but this system does not cover vehicles that are not connected to the ERS. Hence, today's monitoring system needs to cooperate with the internal monitoring system of the ERS. To illustrate how today's monitoring works, WSP has asked the Swedish Transport Administration to provide a such description, see below.

Briefly description of the current monitoring system without ERS and additional needs if ERS is included

Today's monitoring system, operated by the Swedish Transport Administration, is built on an information flow based on primarily input data from cameras or radar to the system’s operators, that then monitor speed limits and information via digital signs and/or radio to the driver. This data is for example used in navigation systems to warn the driver of accidents and queues. The signboards that the Swedish Transport Administration can control can be divided into recommended and mandatory measures. None of these information methods can control the vehicles, which means there are no guarantees about, for example, that the driver follows the speed limit or that a vehicle drives on the wrong side of the road. All this is done at the field level but monitored and managed through systems/traffic managers within the upper levels in the pyramid in Figure 5.

Surveillance – camera monitoring and radar:

- Will most likely be required for conductive road rail and catenary overhead, initially (in the ERS-pilot) this will also be required for inductive coils, but radar might not be required in longer terms
- Information to vehicles and drivers via information road signs are required for all solutions

Management of access via controlled blocking beams and MCS/KFS and related re-routing systems consisting of flexible road signs:

- Both road rail and catenary over-head lines
- No need for induction coils

Tunnels are an exception, as these can be controlled and closed off with barriers remotely, combined with adjustable signs and lane signals during, for example, diversion, to prevent vehicles from entering the tunnel. Also, the fans in the tunnel can be controlled remotely to be able to manage the ventilation of the tunnel.

What is worth keeping in the current system if an additional new system (ERS) is installed?

Many functions are worth retaining in the safety concept with dual components: to monitor the traffic with cameras to see the traffic, digital signs for information, diversion (VDS) and shutdown (KFS) and to have the possibility to have barriers that can stop the traffic if needed. By implementing ERS into the road area, the current process of the traffic management system would not need to be changed, but there would rather be a need for additional functionalities at different levels in the system.

New ideas about features that should be included in a new or modified system?

A technology that can be interesting to use is GeoFencing, which can be used to find out via GPS positioning if a truck is in a zone with rules that must not be violated. The technology can also enable speed limitations and thus prevent higher speeds than allowed for trucks in any given geographical area. This could for example be used to limit speeds in connection to road works. If this system also will be used by passenger cars, it can control more vehicles, as GeoFencing can prevent the vehicle from entering closed lanes or roads. It would be desirable to get information from navigation tools, such as e.g. Google maps, about traffic flows in order to predict when and where there will be queues. Such navigation systems could also keep track of vehicles, including their speed and travel direction. Today's system based on cameras is limited to only monitoring traffic flows which are within each cameras field of vision. With data from navigation tools, traffic management can get a better picture of the flow on the roads and when many vehicles enter the road. If the ERS is out of function, consideration is needed about which actor should be responsible for planning a diversion route. Today, it is not set if the Swedish Transport Administration should have the entire responsibility of providing charging along the diversion or if it can be possible to get this information from other navigation systems (such as Google maps) to support the driver and suggest charging alternatives if necessary.

The current system can also be expanded with, among other things, more information boards for road users about the current situation, digital signs for diversions, and shutdowns. But also, a system that operators can more easily make diversions and shutdowns with, for example, barriers and signals. And of course, a complementary control system for the electric power system that can communicate with the ERS and the monitoring system of the electric road.

SL Metro’s control system as inspiration for ERS monitoring

The new system needed for ERS has to be easy for the traffic management operators to handle. A method that operators could use to manage energy supply (electricity) for a section to a running vehicle, during an accident or other incident, is to use SL (Stockholms Lokaltrafik is the transport authority for land-based public passenger transport within Stockholm County) metro’s control system as a model. SL metro’s control contains digital illustrations with dots showing the entire network of the subway tracks. The SL operators can switch off the supply of one section in the metro via the remote control with a push of a point on the map**.** The system for metro control also shuts off switches to ensure that voltage to the rejected section in the event of rough faults would proceed. Also, surrounding sections that could be a danger to the rescue service can be switched off. That means that the rescue service can get to the site and make protective earthing before starting to work. This way of controlling the feeds to the metro can be emulated to ERS. This enables ERS operators to easily control the feeding in an otherwise complex system where the feeds to the affected section can take place from more than just one direction. Depending on different systems, scenarios must be handled in different ways. This is something that also can vary between the different ERS-technologies. The scenarios/incidents that an ERS system may encounter and need to deal with are:

- How are current systems designed to manage scenarios/incidents on a conventional road?
- How do SL handle incidents in their systems?
- How should they be handled in the future if ERS is included?

Table 5 describes different scenarios/incidents that occur on a conventional motorway, and how current systems handle them. This has then been mapped to how they are managed in the SL system and how they could be managed in a future that includes ERS.

Table 5. Scenarios/Incidents for three monitoring systems.

	Current	SL	Future with ERS
Wildlife accident	In the event of larger wildlife accidents on motorways, it usually gets reported by a phone call that then is managed as an “alarm” up to the NTS-level. Traffic managers then have an action plan for how to address it. This could include among other things, a radio message that goes out, to alert protection hunters and possibly sends a TMA car (Truck Mounted Attenuator) to protect the hunter. Should it be such a serious accident that irritation is needed, the road will be closed.	The operator discards if an accident has been indicated and follows a procedure to remedy the fault	With ERS, wildlife accidents will be handled in the same way as today's surveillance technology. But the operator for ERS can disconnect the section that has been affected by a wildlife accident to provide a safe environment for measures of the accident. Depending on ERS-technology and additional systems that are integrated into that solution, the ERS could of course add additional capabilities in monitor and identify incidents in the field level, which then can be reported up to the NTS-level to follow the process of the action plan.
Unauthorized in the area	Not all national roads have equipment to monitor this. However, if such a situation is identified, either by monitoring equipment or by phone call, it comes as an “alarm” to the NTS-level who then addresses the situation. Actions could include a message is sent to the radio and navigation system if a person walks on a highway. Depending on situation, the highway could be kept open or closed. Other supporting systems could for	If the traffic management receives an indication of unauthorized persons on the track, the supply to the track must be switched off where there is a suspicion that a person is staying. So, the section the person on the track in the south or northbound direction remains de-energized until the traffic management receives a report or can see in their cameras that the person is gone. This will affect the traffic of stopping the traffic until the person	Sections for the ERS that are not currently being activated by a vehicle do not impose a risk of an electrical related accident, hence this is not different from a conventional road. When the system via cameras finds a person on the ERS road, it should inform this to the NTS-level, where traffic operators will address the situation according to the pre-defined action plan. Actions could include sending a warning via radio and to the navigation systems.

	example be door- or intruder alarms, which then sends a message up to NTS-level. Actions could for example be to call Securitas and/or the local operating contractor.	has left or patrol guards finding the person in question. There is a similar procedure for even when derailing with disconnections.	
Crash/accident	Collision or incident with the center strip, can strip off monitoring equipment that has been included in the center strip. The equipment will be temporarily down and could also be long term damaged (need to be replaced) if a collision or an incident occurs against the middle strip. If there are equipment detecting such situations, this would be reported up to the NTS-level. In the event of major traffic accidents, traffic is diverted on existing permanent diversion roads.	The tracks within SL are one-way. And traffic management for SL has such control that prevents collisions between the trains. In the event of an accident, the operator switches off the supply and alerts the rescue service. An electrical work manager from the rescue service controls the electrical safety on-site while the rescue service works and ensures that the workplace is earthed. Back traffic is stopped, if necessary, also traffic on tracks next to it. When reconnecting after the accident has been supplied and any damage to the tracks is repaired, the process is run backward together with an electrical work manager from maintenance who reports when everything is ready for voltage setting. All disconnection takes place via switches and the operator must ensure that the switches are off to secure the workplace for the rescue service. Which in turn can use grounding devices and or use ropes to short-circuit the overhead lines if the switches are switched on by mistake.	Series collisions can be avoided if the system has access to limit the speed of the vehicles in the system and thus create larger gaps. In the event of accidents that are covered, a procedure like that found at SL is needed. With clear areas of responsibility and workflow. All disconnections must be made via switches and disconnectors to create an even safer working environment for the rescue service than what the system at SL can offer. Accidents will still be reported up to the NTS-level and addressed according to the pre-defined action plan. If the traffic needs to be diverted, the distances without charging can be long and electric vehicles might not have enough battery capacity for such long diversion route.
Maintenance/Repairs	Roads are divided into different service levels, and depending on this, they have different set-up times in the event of, for example, an accident or if there is a need of a maintenance action.	Repairs must be carried out immediately while maintenance work takes place during off-peak hours. Which is done according to the Swedish EBR Electrical Safety Instructions (ESA). ESA has a turn order on how safe work should be	The ERS probably needs to end up at a high level for set-up times and a good maintenance plan. Also here as at SL, EBR electrical safety instructions (ESA) are needed to apply for repairs and maintenance

	In case of maintenance works or repairs, the operating contractor will receive a work order and then calls the operation center (NTS), who support with providing access to the facility and if needed, help to give order to turn off lanes etc. depending on the situation and location. The contractor must however always call in and say when a job will be done in the road facility. For tunnels, this might differ slightly as there usually are several involved contractors, e.g. for water and sewage (VA), ventilation, the traffic management system, cameras, cleaning etc., and it requires great coordination between these. On the road network, there is rarely any conflict between operating contractors.	conducted. As an operating order is created, the person responsible for the electrical work will lock the switches so that the work can take place without voltage until the switches are unlocked. When the switches are locked, the traffic line cannot switch on the power, which prevents the risk of injury.	so a safe working environment can be obtained. Should a section be broken, the vehicles can drive past the broken section with their batteries and then reconnect. But the fault on the broken section needs to be repaired so that the system does not have to experience the stress from connections and disconnections that occur with a broken section. These situations will most likely be managed in the same way as the regular procedure for maintenance or repairs in the road area. However, implementing ERS would impose additional contractors to the road network and even though it would probably not become as many nor complex as tunnels, it could constitute an increased need for coordination between these parties.
Power failure	In the event of a power failure, the fixed signs apply, when the digital signs stop working. Information about power outages or faults is given out via radio and navigation systems. In tunnels, there is usually Un Breakable Power Supply (UPS), but this is not the case for road on surface. As part of the action plan at NTS, actions could include sending messages to the local traffic radio in the area.	The system tests through automatic feedbacks at predetermined time intervals to see if the error persists. In the event of a longer fault, the subway train will be stationary until the power returns. And there will be a stop in the traffic, for example with a downed overhead contact line as it is both a physical obstacle and can enlarge the fault.	Like SL, the system will try to feedback to test if the error persists. If there is a downed overhead contact line on the road, the traffic on that section needs to be stopped until the overhead line is repaired. The information about the downed contact line needs to come out as information to the drivers so the risk of injury is reduced, via radio, signs, displays and navigation tools. These actions would be initiated by traffic operators at the NTS-level.
Feedback	The Swedish Transport Administration are not responsible for any electricity grid in current road system. As the power input is quite small, connections are primarily made to the local grid as of today.	The trams feedback to the overhead lines if they do not feel any fluctuations in the network. Which occurs in the event of an imbalance in the system between consumer and producer.	The vehicle must be able to detect if there are unusually high fluctuations in the network or that the ERS technology itself shuts off the section the vehicle passes so no re-feeding can take place. The vehicles that can re-feed

		Trams have as a standard that no feedback comes into the system if there is no voltage in the catenary. Then trams can detect if there is voltage and how much the system can handle	need to have the same technology as the trams, with measuring instruments that can tell how the network is doing. To reduce de-energized conditions due to faults, ERS needs to have dual components (n-1 safety) on its basic components in case something goes wrong. The charge from e.g. trucks can otherwise charge one / several battery / i.e. to save energy when the demand for charging is high and the grid needs to be balanced to meet the demand for charging.
Stationary vehicles	On some of the roads in Stockholm, the traffic management, with a camera, can detect stationary vehicles, due to for example an empty fuel tank or discharged batteries. In these situations, actions at NTS could be to give order to send out a TMA car and to ensure the vehicle can be transported away. However, such monitoring of the facility at the field level is quite rare, and mainly in metropolitan areas. Rest of the road network do, in general, not have such functionalities.	The traffic management can control and have such monitoring that they can see the positions of the trains. They can control and divert. And at times the operators must build queues to be able to move or redirect on the second track.	As conventional roads, a situation of a stopped vehicle in the road may occur. As the ERS collects data on the vehicle's speed, the system can be turned off, limiting the charging for the stopped vehicle. So no damage to stationary vehicles should occur. Otherwise, the same routines apply to an accident, with the operator detecting, switching off and alarming.

Communication systems

Once a new system is introduced, it is generally more self-governing and usually gives fewer wrong decisions for external parties such as the traffic operators. The more parameters that are made available (e.g. stationary vehicles or unnatural charging patterns that may indicate errors for the ERS) the easier it will be with the safety of, among other things, the rescue personnel, and the power systems at the ERS. However, ERS, such as conductive and inductive charging, must deliver and handle this data. Vehicles will probably in a first step charge their own batteries to full, and once they are full, the vehicle can potentially feedback the net surplus energy to the ERS. By handling the feedback, the capacity in ERS can increase and also even out the peaks in the systems.

By reading the vehicle's battery status, ERS could even out the peaks by limiting individual vehicles if needed (if their internal battery capacity is temporarily enough), hence the maximum power of the system will not be exceeded. A predetermined order of priority will most likely be needed, where most power goes to empty batteries and the other vehicles may share the remaining power in the systems.

All road technologies can communicate to vehicles in more or fewer ways. That means that ERS must be able to handle all the information from these technologies. By enabling this, the system can once a stationary vehicle is detected, warn the operators and other vehicles which are or planning to get connected to the electrical road. If the ERS are equipped with cameras, these could be equipped with image management software that also can inform the operators if something happens. By enabling cameras together with technology in the road body, error detection and flow analysis can be made faster and smoother. With both cameras and road technology, the operator can switch off the voltage, re-sign and spread the information to navigators and radio. In the future, there is a potential to enable this through information platforms in the vehicle. In that way, even non-ERS vehicles can take part of the information. The Swedish Transport Administration is also looking at solutions for detecting stationary vehicles with radar, which also could be included in ERS.

WP 2.4 Life cycle analysis and Life cycle cost analysis

The work in WP 2.4 is focused on mapping the current level of knowledge about material and energy use needed, and its related costs, for each ERS technology included in this study and tries to expand the level of knowledge where possible. A mapping of the current level of knowledge and an attempt to further develop the understanding in these areas through interviews and international collaboration have been made. There are several overlapping areas to other chapters in this report, e.g., 2.2 Operation and Maintenance, and conclusions from these areas have been analysed and applied in the context of LCC and LCA throughout this chapter.

A key element is to apply consistent system boundaries for the LCA/LCC-comparison (i.e., use the same principles for which cost and environmental aspects that are included, and not included, for each system) to enable fair comparisons. In this chapter, the focus is solely on the ERS infrastructure, hence a systems perspective also considers the vehicles operating the system and the power supply and transmission are not included.

One conclusion is that the overall ranking between ERS technologies with respect to cost and environmental impact should only be made based on a full systems analysis, as all technologies have strengths and weaknesses which differ throughout the life cycle. Thus, the discussion presented in this work package does not make such conclusions but rather presents data and considerations that should be used to inform system-level analyses conducted going forward.

Investment costs for ERS at commercial scale

The current knowledge regarding the lifecycle costs for ERS is based on a number of theoretical research papers along with the combined experiences from a number of pilot projects with different ERS-configurations and scale (Gustavsson, Martin G. H., Hacker, Florian, & Helms, Hinrich, 2019). In Germany, there are a few implementations of overhead catenary ERS-systems, from where some information is available (Gustavsson, Lindgren, & Mottschall, 2020). As is elaborated on in the TRL assessment, there are other ERS-technologies that have been tested too but at a smaller scale which makes comparisons challenging.

In the existing literature, investment costs are estimated using different methods, primarily depending on the data made available by the actual suppliers. In some studies, particularly slightly older ones when there was a lack of supplier data, the necessary material and components are estimated theoretically based on assumed material volumes. In other studies, data is collected from suppliers.

As part of the planning process for the first permanent ERS in Sweden between Hallsberg and Örebro, where the same technologies were included as in this analysis, investment costs were estimated to be 20-25 MSEK per kilometre two-laned ERS for inductive and conductive ground surface ERS, and approximately 28 MSEK per kilometre two-laned ERS for overhead catenary systems. The cost estimates include all on-site infrastructure; all physical ERS-components located on the immediate road (rail/catenary line, substations) together with necessary service roads, buildings, labour costs and high voltage power lines. The costs for power lines and substations are very similar for all ERS technologies, so the cost difference is a result of varying costs for the overhead catenary lines, inductive coils and conductive rails and their respective control systems.

The estimates were based on data from suppliers together with cost estimates by the local network operator and WSP regarding the substations and high voltage power lines. Costs for vehicles operating on the ERS, system operation costs to control and balance the power system were not included.

The stretch between Hallsberg and Örebro is only 21 kilometres, hence the limited length leads to significant uncertainty regarding these estimates. Technologies are changing rapidly with innovation and prices for input materials and components can vary over time. The actual investment cost will only be known when bids have been submitted by one or more suppliers during the procurement.

There are also several parameters that change when scaling up to longer road networks with more traffic. A major source of uncertainty is the power that each system can deliver to the vehicles, and thereby the level of electrification[3] that is necessary for a given peak load to a system (a section, or kilometre).

In general, the current technologies require that the vehicles trafficking the ERS are equipped with batteries of some size as well as receivers from the ERS, to be able to continue driving on stretches which are impossible or impractical to equip with ERS. The ERS will thus need to be able to power the vehicles trafficking the road at any given moment, plus extra power to charge the batteries. The more power that can be delivered to the system, the more vehicles drive and charge over the same distance, resulting in a lower required level of electrification for a given traffic volume.

The different ERS pilots in Sweden are currently configured and designed for a certain power, which differs between them, but this may very well change with further innovation and testing. Some suppliers indicate that they have ambitions to scale up the transferred power to vehicles, but it is unknown to which level, and the assumptions made have large impacts on the investment costs as a system with double the level of electrification will need twice the volumes of material.

In a recent report from the Swedish Transport Administration (Trafikverket, 2021), assumptions are made concerning the necessary level of electrification for the different systems based on the best available knowledge for each technology, which has large impact on the result. The inductive system is assumed to require a significantly higher level of electrification over the same distance because of lower power output, which increases costs compared to the other technologies as more input materials are needed. The inductive system would, assuming a 100 % electrification level, result in infrastructure costs of 20,8 MSEK per kilometre two-laned ERS. The conductive rail solution is assumed to need a 60-67 % electrification level depending on configuration, with costs ranging from 10,5-15,3 MSEK. The overhead catenary solution is assumed to require a 35 % electrification level, with resulting costs of 12,4 MSEK per two-laned kilometre. The absolute costs in this estimate do not include costs for substations or power lines to connect to the high-voltage grid, so they are not comparable to the Örebro-Hallsberg stretch but is clear how the relative costs between the ERS technologies change significantly when different levels of electrification are assumed. The assumed level of electrification for each technology is also rapidly changing as the technology development is progressing, by for example increasing the power transfer (kW).

Similar assumptions regarding the level of electrification are made in a comprehensive German feasibility study conducted on behalf of the German Federal Ministry of Transport and Digital Infrastructure (BMVI) (Wietschel, o.a., 2017), producing similar results. The inductive technology is assumed to need a 90 % electrification level and is estimated to have the highest investment costs of all technologies, followed by the conductive rail ERS and the overhead catenary ERS respectively.

In summary, the results of the investment cost comparison between systems will be highly dependent on the traffic and peak load for which the ERS system is dimensioned and the power that each ERS can provide to each section of the system. The latter may change rapidly with innovation and is difficult to predict. The traffic and peak load of the systems is clearly a consequence of which roads the ERS will be built for. The consensus is currently that ERS is relevant only for high-traffic roads and highways, particularly from a cost perspective, which implies that the ERS technology with the highest power output has an advantage. However, increased gaps may also increase the required battery size for vehicles, clearly showing the need for system-level analysis for this comparison.

---

[3] The share of the road that is electrified with ERS. If the power output per road section is high enough in relation to the power demand from the vehicles trafficking the road, it is possible to leave “gaps” on the road without ERS, saving materials and cost

Likely maintenance cost variations between systems

Maintenance costs associated with the ERS include both maintenance of the additional components that are added to a road stretch to form the ERS (catenary line, rails etc.) and the costs for additional maintenance of the road structures that arise because of the instalment of the systems. Increased maintenance need of the road structures due to ERS implementation is partly elaborated on in detail in chapter 2.2, and reference is made to that chapter for further details where applicable.

Knowledge about maintenance needs, and the resulting costs, is lower than regarding investment costs, as all pilot systems are relatively new and have not been operating for long. Overhead catenary ERS have been experimented with and tried more than the other systems, which means less uncertainty concerning maintenance. As is noted in a report by the Swedish Research Institute RISE (Gustavsson, M. G.; Alfredsson, H.; Börjesson, C.; Jelica, D.; Sundelin, H.; Johnsson, F.; ... & Lindgren, M., 2021), the costs for increased maintenance need can vary substantially depending on the procurement strategy, and whether one contractor can maintain both the road and the ERS or if several contractors need to be procured.

The Swedish Transport Administration has made an initial comparison of the expected increase in costs for road maintenance and operations between the ERS technologies (Trafikverket, 2020), and finds that the road with an inductive rail system is likely to be associated with significantly lower maintenance costs due to its submerged nature, reducing wear on the system and removing friction and exposure from vehicles and debris. The road maintenance for overhead catenary systems and conductive rail systems are found to be similar. Do note that this report only concerns the road maintenance, not the actual ERS components (catenary line, conductive metal rail etc.).

The overhead catenary lines are exposed to certain external risks that the other systems are not exposed to, such as falling vegetation, and will need regular monitoring to an extent which should be similar to catenary lines for railway applications.

The conductive rail solution will be exposed to significant pressure and friction from passing vehicles and will need a system for clearing debris as well as snow and ice off the rail. Certain suppliers have developed maintenance machinery designed to clear the rail and have connected a heat line to the track to melt snow and ice during winter.

A submerged inductive system is more protected from external risks, but presumably induces higher costs if the electronics should fail for some reason, as the covering asphalt would need to be cleared and then reapplied after repair, which requires machinery and time.

As part of the Örebro-Hallsberg planning project, there were estimates of total annual maintenance costs, including all on-site parts of the ERS, at approximately 0,3 % of investment costs for inductive rail systems beneath the road surface, and 1,6 – 1,8 % of investment costs for overhead catenary systems and conductive rail systems located above the road. The estimates were based on cost assumptions for annual inspections, ERS maintenance and road maintenance including service roads (clearing fallen vegetation, snow ploughing, rail cleaning). The estimates are uncertain and need further investigation, but are in line with the manufacturer statements and, regarding the overhead catenary technology, in line with pilot projects in Sandviken, Sweden and Hessen, Germany.

Furthermore, the estimates assume a 100 % electrification level, which may not be relevant for all ERS technologies as previously explained. Likely, reductions in regular maintenance costs will *not* be proportional to the reduction in the level of electrification, however, as inspection and maintenance usually occur for larger road segments over the same period, and machines will thus need to drive across “gaps” where ERS is not installed to reach the next ERS section. This takes time, and even though fewer stops are needed during the gaps, 50 % electrification will probably not mean 50 % reduced maintenance costs.

This difference in maintenance costs, primarily between inductive technology and conductive technologies, will accumulate and grow over time and becomes sensitive to the discount rate applied in an LCC-analysis. A high discount rate will result in costs over time being valued less, reducing the difference between technologies, and favouring those with lower running costs (maintenance and reinvestment) over time.

Environmental impact from construction and maintenance of ERS

The environmental impact perspective is similar to the cost perspective for the construction and maintenance of the ERS infrastructure. Several studies have been conducted on the environmental benefits of a general transfer from the use of fossil fuels to electricity for vehicle propulsion, but there are few comprehensive LCA-studies also including different ERS systems and their respective infrastructure (Gustavsson, M. G.; Alfredsson, H.; Börjesson, C.; Jelica, D.; Sundelin, H.; Johnsson, F.; ... & Lindgren, M., 2021). According to one review of LCA literature on ERS, there is one study in which a comparative LCA has been conducted for different ERS-technologies, also considering the infrastructure needs (Nordin, Life cycle assessments for electric road systems. Review and analysis of LCA studies (VTI PM D. nr 2016/0505-8.1), 2020).

In this study, Balieu, Chen and Kringos analysed the environmental impact of three ERS technologies over 20 years, including construction, maintenance, and rehabilitation (repaving) for each system (Balieu, Chen, & Kringos, 2019).

- Catenary overhead
- Conductive Rail
- Inductive system

The environmental impact from the *construction phase* is the highest per kilometer ERS from the overhead catenary system according to the study (approx. 141 tCO2/km), as a result of large quantities of steel and copper for the poles and catenary line, followed by the inductive solution (approx. 115 tCO2/km) and the conductive rail solution (approx. 97 tCO2e/km) respectively.

Importantly, no distinction between ERS technologies is made with respect to the level of electrification in this study. If the technologies are differentiated to the required level of electrification, as is elaborated on in the previous section about LCC, the results concerning environmental impact will be different. The results for an LCA will thus change in the same direction as the results for an LCC if the level of electrification changes for a system, even though the magnitude may differ as the relative emissions intensity of each material and energy process used may not be proportional to the relative cost for the same material and energy process.

The environmental impact from *maintenance and rehabilitation* in the study is modelled using the assumptions about traffic load and road deterioration and conclude that the catenary overhead system is associated with the highest environmental impact (in terms of carbon footprint) also including 20 years of maintenance, followed by the inductive system and the conductive rail system respectively. The emissions from maintenance and rehabilitation over 20 years is between 27 % and 82 % higher than the entire carbon footprint from the construction phase, depending on which technology is analysed.

The significant carbon footprint from the operational phase is a strong argument for why a life cycle perspective needs to be adopted when comparing the ERS technologies to avoid sub-optimization.

Service life and replacement strategy for each system and its components

Another key aspect is the service life for each system, and system component. Suppliers are currently speaking of system design for 20-year service life, but due to the lack of practical experience, there is uncertainty as to whether this will occur. Another relevant question is which reinvestment strategy that is likely to be most economically sound: can key components that are worn out be replaced continuously, or should the whole system be replaced even though there are components fully functioning.

If analyzing the ERS systems over longer periods during which repairs and/or reinvestments occur, these questions become relevant. Clearly, the more efficiently the system and each component can be used and not replaced too soon, the lower material volumes will be needed over a given time period. This needs to be analysed from a system-wide perspective as it may still be economically sound to change some components even though they are not fully worn out to save from even greater inefficiencies later.

WP 2.5 Standardization and Interoperability

This section covers standardization and interoperability aspects of ERS, which in this PM have been merged into the same section, due to their synergies and dependencies. Firstly, a general description of the standardization process in the EU is provided, including important organizations and stakeholders in the EU and internationally. Secondly, an overview of the identified, ongoing work on providing new standardizations for ERS is presented. Thirdly, a general view of interoperability aspects in the EU is overviewed, where the focus is on its implications on ERS, for example on aspects that may affect the design of future payment and billing solutions for ERS. This defines a broader context which is developed in more detail in the next section, *WP 2.6 Energy Measurement and Billing*.

Processes for standardization in Europe

European standardizations are mainly initiated by market needs. Hence, the process of developing standards involves many players, industries play a very important role in this context. Formally, European standards are developed through one of the three European Standards Organizations (ESOs) (European Commission, 2022):

1. **European Committee for Standardization (CEN)**
2. **European Committee for Electrotechnical Standardization (CENELEC)**
3. **European Telecommunications Standards Institute (ETSI)**

The ESOs are officially recognized by Regulation (EU) No 1025/ as providers of European standards, where each organization has different purposes (The European Parliament and of the Council, 2012). CEN provides a platform for the development of European standards and other technical documents on various types of products, materials, services, and processes. CENELEC is responsible for standardization in the electro-technical engineering field and helps facilitate trade between countries, access to new markets, and cutting of compliance costs. In addition, it supports the development of the EU single market (free movement of goods, services, capital and people in EU). CENELEC has international market access through close collaboration with the International Electrotechnical Commission (IEC). ETSI produces globally applicable standards for Information and Communications Technology (ICT), including standards for fixed, mobile, radio, converged, broadcast, and internet technologies.

There are other stakeholders involved in the European standardization:

- **National Standardization Bodies (NSBs)** of EU and European Free Trade Association (EFTA) countries are responsible for developing European consensus
- **Small Business Standards (SBS)** is a non-profit organization that reinforces and represents small and medium-sized enterprises
- Consumers, trade unions and environmental interests are represented by **ANEC** (European consumer voice in standardization), **ETUC** (the European Trade Union Confederation), and **ECOS** (Environmental Coalition on Standards). They are important for accountability
- **Public Authorities** develop standards-receptive legislation, issue standardization mandates and public procurement, and provide funding to the ESOs and the NSBs

Industries can get involved directly in the process of standards development through ETSI, but they can only access CEN and CENELEC through National Standardization Bodies (NSBs). The Swedish NSB is called *The Swedish Institute for Standards*, (SIS). This organization is a member of both International Organization for Standardization (ISO) and CEN, and manages a network of experts who work with creation of international standards (International Organization for Standardization, 2022). In this context, SIS acts as project manager for Swedish efforts to develop standards (Swedish Institute for Standards, 2022).

Standardization of ERS

The previous CollERS-report *Connecting Countries by Electric Roads: Methodology for Feasibility Analysis of a Transnational ERS Corridor* concluded that there were no published standards or drafts dedicated to Electric Road Systems, neither on a Swedish, German, or European nor on a global standardization level (Jöhrens, et al., 2021). Since then, several activities on standardization have been initiated on both EU- and international levels for ERS, which are described below.

The Technical Committee CLC/TC 9X is currently working on the development of two important deliverables on the topic of ERS (Carreira da Cruz, 2022). Two working groups have been dedicated to the matter of ERS-standards:

1) **CLC/TC 9X/WG 30**[4] – Current collectors[5] for ground-level feeding system on road vehicles in operation.
2) **CLC/TC 9X/WG 27** – Survey group[6], current collectors on commercial road vehicles in overhead contact line operation.

The working groups are currently developing two Technical Specifications (TS):

i) **CLC/prTS 50717** – Technical Requirements for Current Collectors for ground-level feeding system on road vehicles in operation
ii) **CLC/prTS 50712** – Current collection systems – Technical criteria for the interaction between pantograph and overhead lines on electrified roads

Both TS:s are currently on the verge of reaching the state *First Working Draft* (FWD). The next state is *Formal Vote* (FV), followed by *Published*. The publication is estimated to occur around December 2022, according to Carreira da Cruz.

In parallel, the European Commission has launched a Standardization Request (i. e. a formal request to CEN-CENELEC), in support of a proposed EU regulation repealing Directive 2014/94/EU (AFI-directive, see more details in the next section "*Interoperability in the EU*"), to develop a series of standards related to ERS.[7] The request encompasses the demand on developing European standards containing technical specifications on electric road systems (ERS) with a unified solution for:

A. Inductive dynamic wireless recharging for light duty vehicles (deadline end of 2025)
B. Inductive dynamic wireless recharging for heavy-duty vehicles (deadline end of 2025)
C. Dynamic overhead power supply via a pantograph for heavy-duty vehicles (deadline end of 2023)
D. Dynamic ground-level power supply through conductive rails for heavy-duty vehicles (deadline end of 2024)

CEN-CENELEC predict that they will propose the two TS:s prepared by the CLC/TC 9X as elements to respond to the above request. Furthermore, they have communicated to the European Commission that these two TS:s will contribute, at least in some aspects, to the request made by the European Commission. CEN-CENELEC will continue the discussion with the European Commission and internally, in the CLC/TC 9X working group. Hence, further development will take place in the next months. A schematic summary of the activities is illustrated in Figure 6 below.

---

[4] WG 30 address only vehicle with current collector but is not applicable to vehicles with dynamic or static inductive charging systems

[5] A current collector is an equipment fitted to a vehicle and intended to collect current from a contact wire or conductor rail.

[6] A survey group is a structure of work on topics that are not yet at the same stage of maturity than the ones under a Work Group (WG)

[7] See C(2022) 1710 final (European Comission, 2022)

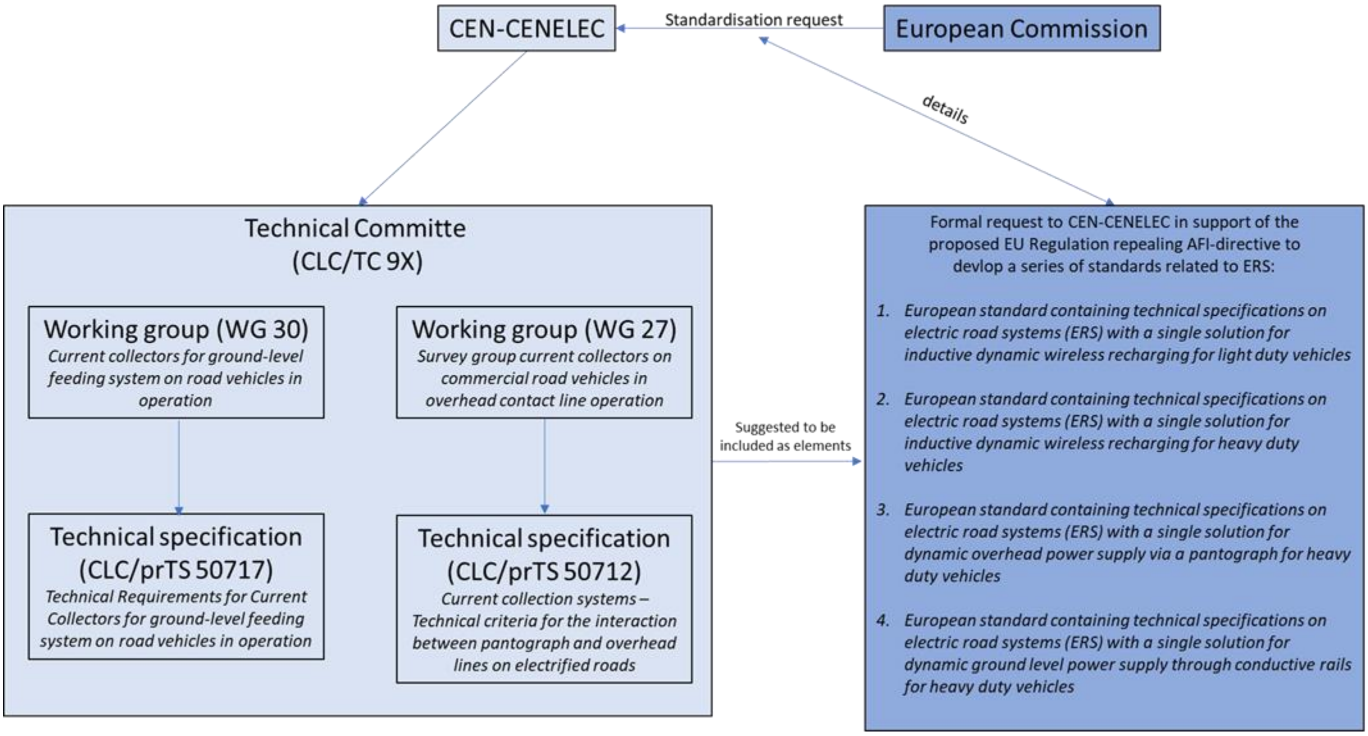


Figure 6. Schematic illustration on activities on standardization of ERS at CEN-CENELEC.

The European Technical Committee CLC/TC 9X also works very closely with the international IEC and each time a new project start at CLC/TC 9X, the project is by default put under parallel work, if not CLC/TC 9X wish to derogate.

In the IEC there is a technical committee TC 69 which is also relevant for the context of ERS as it covers Electrical power/energy transfer systems for electrically propelled road vehicles and industrial trucks (referred to as EV). The scope of the TC is to prepare publications for this specific area, including transfer power/energy from conductive power/energy transfer, wireless power/energy transfer and battery swap. The different publications may cover, but are not limited to (International Electrotechnical Committee, 2022):

- General requirements (e.g. safety, EMC, construction, testing)
- Functional requirements (e.g. charging modes)
- Communication between the EV and the EV supply equipment
- Electrical power/energy transfer between EV and supply network (G2V and V2G)
- Management of the corresponding infrastructures in view of offering the associated value added services.

In above, EV include but are not limited to passenger cars and buses, two and three-wheel and light four-wheel vehicles, trucks and goods vehicles, trailers and special and industrial trucks. Trains, trams and trolleybuses are out of scope of TC 69. Out of the 44 involved countries, 30 of them are participating countries and 14 are observer countries. Both Sweden and Germany are participating countries.

Within TC 69 there are several subcommittees and working groups, which are summarized in Table 6 below.

Table 6. Summary of TC69's Subcommittees and Working Groups.

Label	**Title**
Working Group	
WG 7	Electric vehicle wireless power transfer (WPT) systems
WG 9	Electric vehicle charging roaming service
WG 10	Light electric vehicles conductive power supply systems
WG 12	Electric Vehicles conductive power/energy transfer system
WG 13	Electric vehicle battery exchange infrastructure safety requirements
WG 14	EV supply equipment with automated connection of a vehicle coupler
WG 18	EV Supply Equipment Vocabulary
Project team	
PT 61851-23-1	Electric vehicle conductive charging system - Part 23-1: DC Charging with an automatic connection system
PT 61851-23-3	DC electric vehicle supply equipment for Megawatt charging systems
PT 61980-4	Interoperability and safety of high power wireless power transfer (H-WPT) for electric vehicles
PT 62576-2	Electrical characteristics test methods of EDLC Module for Electric road vehicles
PT 63243	Dynamic electric vehicle wireless power transfer systems
PT 63380	Local Charging station management systems
PT 63381	Dynamic wireless power transfer
Maintenance Teams	
MT 5	Maintenance of IEC 61851-23 and IEC 61851-24
MT 61851-21-2	EMC requirements for off board electric vehicle charging systems
MT 62576	Electrically propelled vehicles, energy storage, electric double-layer capacitors and hybrid capacitors
Joint Working Groups	
JWG 1	Vehicle to Grid Communication Interface (V2G CI) linked to ISO/TC 22
JWG 11	Management of Electric Vehicles charging and discharging infrastructures linked to TC 57
JWG 15	Distributed energy storage systems based on Electrically Chargeable Vehicles linked to TC 57, TC 120,
JWG 69 Li	TC21/SC21A/TC69 - Lithium for automobile/automotive applications Managed by TC 21
JWG 69 Pb-Ni	TC 21/SC 21A/TC 69 - Lead Acid and Nickel based systems for automobile/automotive applications Managed by TC 21
Advisory Groups	
AG 16	Chair’s Advisory Group
Ad-Hoc Groups	
ahG 17	Interoperability and safety issues of using charging adapters between DC charging systems

In TC 69 ongoing work as of February 2022 included 38 work programmes covering numerous subjects in different stages and with forecasted publication dates spanning from 2022 to 2025. At the same time, there were also 24 available publications from TC 69.

There is an ad-hoc group working on inductive power transfer and interoperability aspects for Railway at IEC TC 69 level, that goes under the name “Interoperability and safety of dynamic wireless power transfer (WPT) for railways” (Miglianico, 2022). This group might be relevant for the context of ERS, however, based on general information on the website, this has not been confirmed.

Interview with Scania on ERS impact on trucks, standardization and development

This subsection discusses the impact that the emergence of Electric Road Systems has on ERS-adapted trucks, corresponding ERS-standardization, and ERS testing activities, as seen from the truck manufacturer Scania´s perspective. The information is gathered mainly from an interview with Christer Torén (Project Manager for electric road technology) at Scania made by WSP in March 2022 (Torén, 2022). The focus of the interview was on the solution with dynamic overhead power supply, an area of expertise where Torén has extensive experience.

Scania's engagement in standardization

Scania is a global provider of transport solutions including trucks and buses for heavy transport applications. The company is owned by the Volkswagen Group and has headquarters in Sweden. It is more involved in the development of ERS technology than most other truck manufacturers, according to Torén. Not only are Scania trucks used in ERS testing activities in both Germany and Sweden, but Scania is also active in standardization through the working group DKE 451 which is part of the VDE-network (VDE Institute, 2021). This group consists of experts and representatives from the German industry and universities, and Scania/Torén as the only non-German member. The group's main objective in the context of ERS is to facilitate and increase the pace of the standardization work, and to contribute by identifying standardization issues to be solved by the responsible working groups (Torén, 2022).

The European long-term goal is to develop three types of ERS standards: inductive dynamic wireless recharging, dynamic overhead power supply via a pantograph, and dynamic ground-level power supply through conductive rails. For resource reasons, Scania has currently chosen to focus on the overhead power supply solution. The logic behind this decision is that the chosen technology is sufficiently mature (Torén, 2022). Similar knowledge is already at hand from trolleybus and train technology. Apart from the gain from similar experiences, some cumbersome difficulties can be avoided when choosing the catenary system. Inductive dynamic wireless recharging is said to at present suffer from low efficiency, and the fact that there is always some natural degree of movement in the ground could be a problem for the conductive rails solution (Torén, 2022).

If in the future, Scania will identify a sustainable business case for either one of the other two solutions, Torén thinks that the impact on the trucks from switching from one standard to the other will not be that large. Once there are test results and experience from the catenary solution, the vehicles can easily be adapted and re-built to fit the other standards (Torén, 2022). If there is a future demand for trucks with multiple ERS capabilities, Scania will produce them (Torén, 2022). This means that the same ERS-adapted truck will be able to overcome potential interoperability problems which might occur if different EU members choose to implement different ERS-standards. Nevertheless, such multicapabilities will inevitably increase the cost and therefore the price of ERS-adapted trucks. Will the haulage companies still demand multicapable trucks? What happens if, e.g. Germany chooses one standard and France another one? Trucks capable of only one standard might not be operable electrically all over Europe and hence parts of the ERS-infrastructure investments could become underutilized, due to limitations on technical interoperability.

The ERS standardization landscape

Two standardization domains are applied to ERS-adapted trucks with catenary solution: ISO and CENELEC. Figure 7 sketches the main building blocks of the trucks, and the corresponding standards.

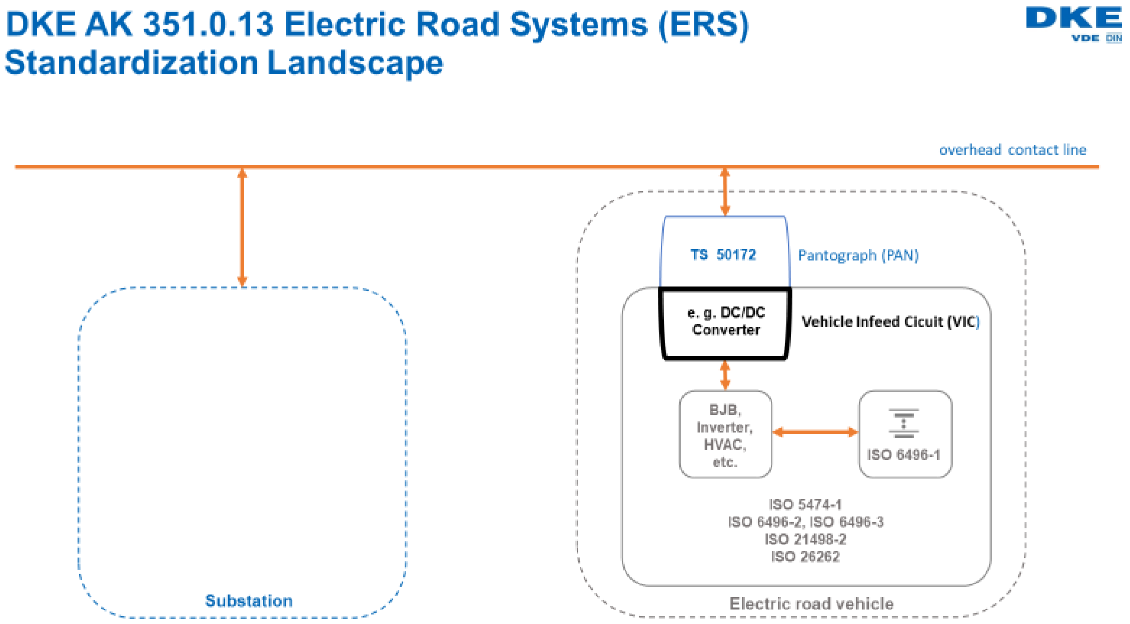


Figure 7 The standard domains ISO and CENELEC, on vehicle, pantograph, Vehicle Infeed Circuit, and Enable Device. Source: DKE/VDE.

Before discussing the domains in more detail, some technical definitions are required here. Located between pantograph and truck are the *Vehicle Infeed Circuit* and the *Enable Device.* A *Vehicle Infeed Circuit* is a contactor and a DC-to-DC converter, i.e. it can convert a source of direct current from one voltage level to another. An *Enable Device* is basically a sensor that checks whether there is a contact line above the vehicle or not and decides when the PAN should be in upright position. The following definition is given in TS50712:

“An *Enable Device* controls the use of PAN (rising and lowering) depending on various inputs, such as drivers command, vehicle states and data gathered by sensors connected to the enable device. Thus, it is responsible for the functional safety decision whether it is safe to connect and stay connected or not.” (CENELEC CLC/TC9X/Sec1302/CD, 2021)

The vehicle part is governed by ISO standards (International Organization for Standardization, 2022). Adaptation of the vehicles to ERS-technology has not resulted in any new ISO-requirements on the actual trucks (Torén, 2022). However, new standards are being developed for the pantograph (PAN). The specification of the interface between PAN and wire belongs to the IEC-standards (International Electrotechnical Commission, 2022). It is named CENELEC TS 50712 and the first draft is from June 2021. The specification is very elaborated and detailed. It contains definitions of the interface between PAN and infrastructure, general characteristics which are to be applied to the ERS PANs, system architecture including hardware, recommendations of a common electrical safety concept, information on dimensioning, control interface description, specification of tests of the PAN, etc. The overhead contact line is specified by the standard EN 50119.

Scania’s engagement in testing the catenary solution

According to Torén (2022), only the catenary ERS solution is currently being developed and tested in Germany, while e.g. France has shown higher interest in the solution with ground-level power supply through conductive rails, and the solution for inductive dynamic wireless recharging. Torén also claims that Germany is five years ahead of all other EU members in testing ERS, because of the possibility to re-use standardization and experience from similar technologies which include pantograph. Scania has decided to concentrate its development efforts on the German activities. Initial cooperation with one single EU member is perceived by Scania to be the most efficient way to go. Marketwise, Germany is also at the forefront according to Torén. The country has budgeted non-fossil fuel infrastructure investments for four billion Euro in total for 2022 and 2023. The amount is to be split between investments for static chargers, fuel cells and Electric Road Systems. Three German regions are designated for ERS tests, one close to Munich, one near Frankfurt am Main, and one in the northern part of the country. Each region has three billion Swedish kronor at its disposal. Tests will only be performed on highways and not on smaller roads.

Impact on standardization from proven train technology

The catenary solution suffers from the often referred drawback that it cannot be utilized by other vehicles than trucks. Automobiles are completely excluded as users of catenary ERS. However, there are also advantages. One of them goes back to the substantial similarities between catenary ERS and old, proven technology of trains and trolleybuses. By studying existing solutions, crucial and potential ERS-problems can be identified at an early stage and in an efficient way, even though the preconditions are not exactly the same. Many of the issues found in this way are about security. However, the main lessons learned from train solutions concern the areas *voltage levels* and *transients*. Many of these insights influence the standardization work.

ERS is today operated on 600 V direct current (DC), which is the same as for the Stockholm metro. Regular long-distance trains are normally run on alternating current (AC) but some countries use DC, e. g. Belgium. Experience from DC-operated trains is of particular interest in the ERS-context. An important, general fact which must be considered, is that more power increases the capacity of the Electric Road System, meaning that more trucks can be handled at a given current level. The higher the ERS voltage, (with a fixed level of current), the greater the ERS power. Hence, there is an incentive to increase the voltage of ERS. Counteracting are the requirements on security. The ISO standards require increased security measures for voltage levels from 1500 V and upwards. As a golden mean, the ERS standardization aims at a level of 1200 V to increase the capacity as much as possible but at the same time avoid the necessity of more rigorous security measures (Torén, 2022). Currently, examples of existing standard voltage levels are 600 V and 1500 V. 1200 V is not standard yet.

Furthermore, there is the issue of transients, i.e. due to thunderstorms. A transient is a high amplitude, short-duration, voltage surge. In the standardization work, an assessment must be made of how large voltage levels the Electric Road Systems, and the adapted trucks, are expected to manage. According to Torén, there are recommendations and norms from standards of similar technology that could be re-used in the context of ERS, but the exact decisions of what to use remain.

Technical interoperability between EU Members States

Each of the three ERS solutions is to be uniform for all European countries in terms of standards. No exceptions or country-specific standards are to be included in the specifications (Torén, 2022). This means that ERS and its adapted trucks must be able to cope with all country-specific requirements and weather conditions. This is reflected in the standards. There will, however, probably arise challenges if different EU members choose different ERS-technology, as already stated. Even if all countries were to go for the catenary solution alone, interoperability problems could still occur. Some of them can, however, be eliminated if identified in time. One issue is the maximum permissible truck height. It currently varies in Europe, depending on the country (Torén, 2022). Even though most countries allow a truck height of up to 4 meters, there are exceptions. In Sweden, there is no limit at all, except for the fact that bridges allowing for less than 4.60-meter trucks must be provided with a warning sign. Great Britain allows trucks with heights over 4 meters. From a standardization point, this aspect is a challenge for the catenary system as the pantograph must allow for contact with the overhead lines which could be mounted at different levels above the road in each country.

Interoperability in the EU

This section discusses current regulations and proposals for new regulations within the electrification of road transport. It then continues with a discussion of the implications of interoperability on ERS. Central is the EU's ambition to provide a seamless, trans-European transport network (TEN-T). All parts of the system must fit together regardless of the country, i.e. the use of ERS must be smooth also when the electric trucks cross geographical borders. This fact applies to purely technical as well as legal and economic matters. The payment systems form an important part of the ERS solution. The domestic financing of ERS is another subject of great significance. Key to successful ERS interoperability are standardized, technical specifications, and uniform financial solutions. Described below, is how stationary charging shall be implemented, including both ad-hoc payments and contract-based payments. Specified is also how the used energy from electric roads should be paid. This part has implications for the Swedish Transport Agency since it is expected to manage invoicing of the electricity through existing charging systems and to do billing. The section is concluded with a discussion of laws and regulatory aspects regarding environmental issues which affect the implementation of ERS.

When introducing ERS, legal and interoperable aspects need to be analysed and accounted for. The Commission's package "*Fit for 55*" is such an aspect. It aims to implement the EU's raised climate targets by 2030 and proposes measures to reduce EU net emissions by at least 55 % compared to 1990 levels. It also sets the direction for the long-term climate goal of climate neutrality by 2050. As part of these goals, the European Commission (henceforth also "the Commission") promotes market growth of zero- and low- emissions vehicles. In particular, it seeks to ensure that citizens have access to adequate infrastructure to charge these vehicles, applicable for short as well as long journeys. In addition, from 2026, road transport will be covered by *emissions trading*, setting a price on pollution, stimulating cleaner fuel use, and re-investing in clean technologies."

Furthermore, the Swedish government inquiry *Utfasningsutredningen* for phasing out fossil fuels noted that an extensive electrification of road transports is much needed (Utfasningsutredningen, 2021). The inquiry claims that government support is needed to enable a shift, especially for long distance heavy goods vehicles (HGV) that need both stationary and dynamic charging.

Current regulations

Several EU directives and regulations affect the planning of ERS. Besides implementing relevant EU law, Swedish law also includes a few complementing regulations affecting the establishment of ERS. Table 7 and Table 8 display the most relevant EU and Swedish legal acts. However, it must be noted that this is an area of law under reconstruction. The European Commission are either reviewing or has proposed a revision of the EU law shown in Table 7. In Sweden, a governmental inquiry (SOU 2021:73) (Elvägsutredningen, 2021) has suggested changes to Swedish law that remove obstacles regarding governmental investments in ERS infrastructure. For instance, they suggest a clearer articulation in the Road act that an ERS is a road facility as well as a division of responsibilities among the actors of the ERS. The relevant Swedish acts are shown in Table 8. In all, what is valid law in the EU and Sweden today may be outdated "tomorrow".

Table 7. EU law

Law	Description
TEN-T regulation (EU) No 1315/2013 (The European Parliament and the Council, 2013)	Establishes guidelines and priorities for the development of a trans-European transport network comprising of the comprehensive network and of the core network. In the process to be revised.
ITS-directive 2010/40/EU (Commission Implementing Regulation (EU), 2010)	The framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport. Contains definitions of e.g. compatibility, interoperability and standard.
Alternative fuels infrastructure (AFI) directive 2014/94/EU (Directive 2014/94/EU of the European Parliament and of the Council, 2014)	The AFI-directive is the main policy instrument for the EU to implement alternative fuels infrastructures. In process to be replaced by a regulation.
Eurovignette directive 1999/62/EG (Directive 1999/62/EC of the European Parliament and of the Council , 2015)	Charging of heavy goods vehicles for the use of certain infrastructures. The charge is currently in proportion to the time that the infrastructure is used.
Amended by Directive (EU) 2022/362	The Directive (EU) 2022/362 is amending 1999/62/EG and include a replacement of time-based charges with distance based.

Table 8. Swedish law

Law	Description
Ellagen (1997:857) (*Electricity act*)	Regulates electricity facilities and some cases electricity trading. An electricity facility is for producing, transmission or use of electricity.
Väglag (1971:948) (*Road act*)	Regulates construction and maintenance of public roads
Lag (2014:52) **om infrastrukturavgifter på väg** (*Road infrastructure charge act*)	This law applies for a) infrastructure fees at public roads other than ferries, and b) infrastructure fees for heavy freight vehicles on private roads being part of the TEN-T road network in Sweden or that are highways.
Lag (2016:915) **om krav på installationer för alternativa drivmedel** (*Act on requirements for installations for alternative fuels*)	Incorporates AFI-directive into Swedish law. Regulates installation of alternative fuels and information to users.
Elsäkerhetslagen (2016:732) (*Electricity security act*)	Regulates safety to reduce risks of personal or property damage. An electrical installation refers to an installation for the production, transmission or use of electricity with the special objects that are in the installation and that are needed for its operation.
Elsäkerhetsförordning (2017:218) (*Electricity security regulation*)	An electric road is in this regulation defined as a road which is supplemented with an electrical installation intended for the transmission of electrical energy to moving vehicles.

Förordning (2007:215) **om undantag från kravet på nätkoncession enligt ellagen** (1997:857) *(Regulation on exemptions from the requirement for a network concession according to the Electricity Act)*	This regulation state that an internal network may be built and used without a network concession, if the purpose of the lines is to 1. mainly meet the electricity needs of vehicles, or 2. meet the electricity demand for a traffic route or a municipal road with associated facilities and the lines are laid within or in the immediate vicinity of the traffic route or the municipal road.

Regarding current Swedish laws, Trafikverket (2021) concluded that they are not legally allowed to construct electric roads because they would need a network concession according to the Electricity act. They also concluded that no one else has the authority because only Trafikverket has the authority to build national public roads according to the Road act. Recently there was however an exception in the requirements for a concession when the primary purpose is to charge electric vehicles.[8] These aspects have been further specified and detailed in the government investigation of ERS (Elvägsutredningen, 2021), that was presented in autumn 2021. For more information regarding the investigation, see the next chapter *WP 2.6 Energy Measurement and Billing* where a summary of key insights is presented.

Purpose and definition of interoperability

Interoperability is defined as: "...the ability, including all the regulatory, technical and operational conditions, of the infrastructure in a transport mode to allow safe and uninterrupted traffic flows which achieve the required levels of performance for that infrastructure or mode".[9] For transport firms to be able to operate across borders, there must be a certain level of interoperability. The work in work package 3.2 has therefore been focused on legal aspects of interoperability and the processes that are ongoing on EU level to ensure infrastructures for alternative fuels and harmonization of payment systems (from a broader perspective as an introduction to work package 2.6, which is focused more solely on ERS).

When introducing new or alternative fuel infrastructures within the EU there are several issues to consider. One of them is that EU has the ambition to have a trans-European transport network (TEN-T) with a high level of interoperability (TFEU, 2008)[10]. Actions by the European Union in this area should promote interconnection and interoperability of national networks as well as access to such networks. When the Commission acts in this area of law and proposes changes to a legal act, the aim must be to promote interconnection and interoperability. The general requirement in TFEU is further explained in for example Directive 2014/94/EU (also known as the alternative fuels infrastructure (AFI) directive) which sets the ambition to proactively avoid a fragmentation of the internal market due to uncoordinated market introductions of alternative fuels (recital 10) (The European Parliament and the Council, 2014).

When the "ideal" EU ERS approach is discussed, the idea is that all ERS users should be able to drive electric vehicles through a sequence of EU Member States, for example from Rome to Stockholm, with a largely uniform payment system and only one contract with one single ERS infrastructure operator (Hartwig, Bußmann-Welsch, & Lehmann, 2020). This ideal state is, however, probably rather distant in the future.

---

[8] Förordning (2007:215) om undantag från kravet på nätkoncession enligt ellagen (1997:857) § 22b

[9] See the TEN-T Regulation art. 3(o) (The European Parliament and the Council, 2013).

[10] TFEU – Treaty of the Functioning of the Euopean Union

Requirements and issues

EU Standardized Specifications for ERS

The creation of a single European transport area is discussed in art. 4 of the TEN-T Regulation (The European Parliament and the Council, 2013). EU-law requires that the Commission supports this view by coordinating policy frameworks and by providing long-term predictability for public and private investments in transnational matters. The proposal for replacing the AFI directive with a AFI regulation is a step in this direction. To allow for harmonization common definitions are needed. In art. 2(17) ERS is defined as:

> *“a physical installation along a road that allows for the transfer of electricity to an electric vehicle while the vehicle is in motion”.*

However, ERS is not the focus of this proposal, it is only referred to as an emerging technology. To be able to regulate this type of technology, the Commission asks for the mandate to adopt acts in accordance with art. 290 TFEU (TFEU, 2008), to norm technical specifications for areas where common technical specifications are currently lacking. This includes the communication between electric vehicle and recharging point, and the communication between recharging point and recharging software management system (back-end). The latter is meant the communication related to the electric vehicle roaming service and the communication with the electricity grid (recital 53 (proposal of AFIR)).

The Commission also considers it necessary to define an appropriate governance framework and to define the roles of the various actors in the vehicle-to-grid communication ecosystem. If this part of the proposal is approved, the Commission will be able to harmonize the establishment of the ERS infrastructure. If the Commission were given the opportunity to advance delegated acts on standardization, the degree of technological maturity would most likely be strengthened and sufficient maturity be achieved within a shorter period than otherwise (Hartwig, Bußmann-Welsch, & Lehmann, 2020). Nevertheless, it cannot be ruled out that standardization might lead to several alternatives, and this may result in semi-interoperability where different parts of the EU choose different ERS technologies. Even if this scenario becomes a fact, the worst-case scenario with heterogeneous implementation across the union would be limited (Hartwig, Bußmann-Welsch, & Lehmann, 2020).

EU Interoperability Issues

An issue regarding interoperability is that Member States might have different definitions of the term *Road* in their legislation. Not all of these may include ERS infrastructure. EU law gives a wide definition of *Road* that does not contradict development and integration of traditional road networks with other types of infrastructure elements, (refer to Art. 17 of Regulation No.1315/2013/EU) (The European Parliament and the Council, 2013). Since the revision of the TEN-T Regulation is ongoing and one of its objectives is to coordinate this regulation with the new AFI regulation, it seems likely that the wide definition will remain (The European Parliament and the Council, 2014). ERS might well be mentioned in a future version of the definition of “Road”.

Another interoperability issue is how Member States shall finance the construction, operation, maintenance, and development of ERS. This problem is addressed in the proposal for a revision of the Eurovignette Directive (Directive of the European Parliament and of the Council amending Directive 1999/62/EC on the charging of heavy goods vehicles for the use of certain infrastructures) (The European Parliament and the Council, 2017). In recital 25(a) the Commission emphasizes the need to allow Member States to finance installations for energy and fuel to low- and zero-emission vehicles. The Eurovignette Directive should not prevent Member States from charging the use of such facilities for financing purposes. For this reason, art. 9(1) is amended: Member States should not be prevented from applying, on a non-discriminatory basis, charges specifically designed to finance the construction, operation, maintenance and development of installations, embedded in, or deployed along or over roads, providing energy to low- and zero-emission vehicles in motion and levied on such vehicles.

Stationary Charging Infrastructure and Distribution Grids

Art. 33 of Directive 2019/944 states that charging points may not be part of the distribution grid, but that a facilitated connection to it should be ensured (Art. 1) (The European Parliament and the Council, 2019). Distribution grids and charging points should be two separate infrastructures and not operated together (Art. 2). A comparable separation must also apply to ERS, but with a separate regulation that reflects the systemic characteristics of ERS. There is a predominant opinion in the professional public that ERS technology needs a regulation that largely excludes it (like charging points, cf. Section 3 No. 25 EnWG) from the network regulation of Directive 2019/944 and sufficiently takes into account its specific characteristics.

The proposal of an AFI-regulation aims to ensure the availability and usability of a dense, widespread alternative fuels infrastructure network throughout the EU. For electric heavy-duty vehicles, an electric, *stationary* charging infrastructure is suggested (see art. 4). According to the proposal, charging points are needed every 60 km along the TEN-T core network and at least 1 400 kW installed capacity per charging station must be provided by 2025 and 3 500 kW by 2030. On the TEN-T comprehensive network, the goal of 1 400 kW must be reached in 2030 and the goal of 3 500 kW to be reached in 2035. The charging points are here required every 100 km. Charging points should be located in secure parking lots in cities and agglomerations on the trans-European transport network, i.e. in urban nodes. Such charging points could be used by, for example, urban delivery trucks. The intention with these proposed minimum requirements is to provide an infrastructure that allows for full interoperability and interconnectedness for electric vehicles, across all transport types and in all Member States. If the Commission's proposal is approved, it will affect the development of ERS in terms of technical competition and harmonization.

Regulation (EU) No. 913/2010 specifies that "rules for the establishment and organization of international freight corridors for competitive rail freight transport shall be established with the aim of creating a European rail network for competitive freight transport" (Art. 1 para. 1) (The European Parliament and the Council, 2013).

The Swedish government inquiry for ERS (Elvägsutredningen, 2021) suggested that the user costs of energy should be handled in the same way as for railways. For railway operations, the Transport Administration procures electricity and delivers it to railway companies for a non-profit price. The Swedish Transport Agency was in early 2022 assigned by the government to consider and suggest a model for handling of user costs and other debiting aspects.

Payment Systems

Ad-hoc Payment and Contract Based Payment

In art. 5 of the proposed AFI-regulation, a slight harmonization between payment systems is suggested for the charging infrastructure. The Commission proposes that operators of publicly available charging stations shall be free to purchase electricity from any Union electricity supplier. Operators should allow end users to charge their electric vehicles on an ad-hoc basis, with a payment instrument commonly used in the Union. For charging points with a power output exceeding 50 kW, operators shall accept electronic payment through terminals and devices used for payment services. A minimum requirement is use of devices such as payment card readers, and devices with contactless functionality.

When operators offer automatic authentication at their publicly available charging points, they must ensure that end users have the choice not to use this authentication, but to either recharge their vehicle on an ad-hoc basis or to use another contract-based charging solution offered at the charging point. Operators shall also clearly display the ad-hoc price and all its components at all publicly accessible recharging stations. As a minimum requirement, the following price components shall be clearly displayed, if applicable at the recharging station: price per session, price per minute, and price per kWh.

The Swedish government inquiry for ERS suggested that the Swedish Transport Agency should use existing charging systems in order to facilitate the introduction of electric roads in Sweden (Elvägsutredningen, 2021). The Agency's existing charging system is based on invoicing, and the government inquiry has proposed that the Agency should additionally be allowed to bill users of electric roads. If the authority were to be given the opportunity to use other, more efficient charging systems such as account-based handling, it would be considered an alternative. Collection of data regarding the use of ERS is proposed to be handled by the Swedish Transport Administration. Thus, the authority would be responsible for the contractual relationships with the owners of the electric road vehicles since it is accountable for the electric road system itself.

It is noteworthy that when the European Commission suggested payment system for electric charging stations, invoicing was not mentioned at all. It is plausible that the Commission aims to harmonize the payment system for electric charging stations and ERS, which could preclude the ERS Commission's idea of using existing payment systems. On the other hand, the newly revised EETS Directive EU 2019/520 allows Member States to use invoicing as payment system, (see for example recital 42) (The European Parliament and the Council, 2019). Since the use of ERS is similar to the use of standard road infrastructure, the government inquiry proposed payment system may still be acceptable (Elvägsutredningen, 2021).

Summary

Several processes regarding standards and regulations are currently ongoing, which makes the overview in this section a snapshot of the current state of affairs. The aim has been to explain the processes and ambitions.

The processes of standardization of ERS are ongoing within CEN-CENELEC and IEC. The technical committee at CEN-CENELEC (CLC/TC 9X) is estimated to publish technical specifications (for ground-level feeding systems, and pantograph and overhead lines) by the end of 2022, whereas the technical committee (TC 69) at IEC is estimated to publish documents until 2025. The request from the European Commission to CEN-CENELEC about drafting unified European standards has deadlines by the end of 2023 (for overhead lines and pantograph), the end of 2024 (for conductive rails) and the end of 2025 (for inductive dynamic charging).

The request from the Commission comes in light of the process of the new AFI regulation (repealing the AFI directive). This process, in turn, was initiated by the EU “Fit for 55” package in which the goal is to reduce transport emissions in the Union by 90 % until 2050 compared to 1990.

However, ERS is not the focus of the proposal for AFIR, it is only referred to as an emerging technology. To be able to regulate this type of technology, the Commission asks for the mandate to adopt acts in accordance with the Treaty of the Functioning of the European Union art. 290 (TFEU, 2008), to norm technical specifications for areas where common technical specifications are currently lacking.

In addition to a new AFI regulation, the Commission has proposed revisions for the TEN-T regulation and the Eurovignette directive. The latter is set to be changed from time-based to distance-based charges and include also cars and light duty vehicles.

As for the standardization processes, it is noteworthy that the industry is not a driving force. Compared to other sectors, for example, telecommunications, the industry has not developed standards (or rather financed the development of standards) before product development. A plausible reason is that the industry is uncertain of the profits to be made and is thus reluctant to finance the standard development.

A question that is still looming is whether the different standardization timelines of the various technologies could have an impact on the choice of technology. Overhead lines and pantograph seem to have a standard in place before the other technologies, but decisions on a large-scale roll-out would preferably be made with potential long-term efficiency in mind as well. Swedish official agencies, Trafikverket for instance, are concerned about the risk of lock-in effects otherwise (Trafikverket, 2021; Trafikanalys, 2021).

Under all circumstances, the impact of the choice of technology seems to be much larger on the infrastructure than on the ERS-adapted trucks. According to Scania, the company is ready for all three technical ERS-alternatives, even though its current development and test activities are focused on the catenary solution (Torén, 2022). Switching from one standard to another is not a complex matter for the ERS-truck manufacturer. If there is a demand from the market for a specific solution and standard, Scania claims they will deliver (Torén, 2022). When it comes to standardization, Scania is not a main driver. However, the company is still contributing to this area, e.g. by providing comments on standardization drafts. It is also an active participant and important contributor to the testing of the catenary solution. Much knowledge is retrieved from train technology, according to Scania, especially in the areas of voltage levels and transients. This knowledge has been valuable input to the standardization work.

WP 2.6 Energy Measurement and Billing

This work package has been divided into three separate parts. First, a brief literature review of the already established intermodal road toll system European Electronic Tolling Service (EETS) and how it is implemented in Sweden is presented. Second, technical functionalities for each ERS-technology concerning energy measurement and billing are specified. Lastly, insights from the Swedish government inquiry ("Elvägsutredningen") are summarized with a focus on aspects that might affect the requirements for energy measurement and billing systems for ERS (Elvägsutredningen, 2021).

Synergies with already established intermodal road toll systems (EETS)

If ERS is deployed on a larger scale, there will be a need for a system of billing and payment to support intermodal transport. This is already something that is being discussed within the EU and hence the vision is that the nationality of an individual vehicle should not limit its ability to charge on the ERS, no matter which country it is driving/charging in. When designing such a system for ERS, there are already some similar intermodal systems in operation (in other applications) in the market today, where inspiration can be drawn from. The system that is usually referred to when ERS is discussed, is the European Electronic Tolling Service (EETS) which is described more in detail below.

European Electronic Tolling Service system

The EETS system ensures interoperability of tolling services across the entire European Union road network. It enables road users to easily pay tolls in all EU with only one subscription contract with one service provider. The system requires a single on-board unit (OBU) to be installed in the vehicle. Beyond limiting cash transactions and eliminating cumbersome procedures for occasional users, the OBU can be utilized for various other added value telematic applications and services, such as eCall, real-time traffic and travel information (European Commission, 2021).

The EETS system is not intended to replace national or local electronic toll services, but rather to complement them. This is enabled by open and public standards, available in an interoperable, non-discriminatory basis to all system suppliers covering all forms of Electronic Toll Collection (ETC) (Directorate General for Internal Policies, 2014).

A single contract with one EETS provider should allow the users to pay their tolls in all EETS domains in accordance with the Directive 2004/52/EC (The European Parliament and The Council, 2021-01-13). The directive set scopes and standards to be used in the Electronic Tolling Free System (ETF) and was followed by the policy document issued by the EC in the form of the Commission Decision of 6 October 2009 on the definition of the European Electronic Toll Service and its technical elements (European Commission, 2021). Both policy documents are reviewed, with the last consultation ending on October 10th, 2016.

By 2004 there were six main electronic fee collection systems currently in use (Directorate General for Internal Policies, 2014):

1. Automatic Number Plate Recognition (ANPR) - a mature technology that uses video cameras for vehicle identification.
2. Dedicated short-range communications (DSRC) technology - based on bidirectional radio communication between fixed roadside equipment (RSE) and a mobile device (OBU) installed in a vehicle.
3. Radio Frequency Identification (RFID) - the most used Toll Collection system in the United States (US), relying on radio waves to identify devices.
4. Global Navigation Satellite Systems (GNSS) technology for toll collection purposes – an emerging technology that uses the vehicle's position data to measure the use of the road in order to determine the charge.
5. Tachograph-based tolling - the system used in Switzerland - records the mileage driven by the user through an OBU connected electronically to the vehicle´s odometer.

6. Mobile communications (GSM and smartphones) tolling systems - still in an embryonic stage but have significant potential going forward.

Each technology differs in performance, enforcement, accuracy, cost evaluation and interoperability.

Mainly three use cases are identified as relevant for tolling systems (European Commission, 2021):

1. Levy tolls with OBU based on DSRC
2. Levy tolls with OBU based on GNSS
3. Levy tolls based on ANPR

The EFC-directive attempts to standardize European toll collection systems and as a result, systems deployed after January 1st, 2007, must support at least satellite positioning, mobile communications using GSM-GPRS or 5.8 GHz microwave technology. Furthermore, as the Regulation on the European Electronic Toll Service (EETS) was issued by the European Union, the regulation needs to be implemented in all Member States from 19 October 2021 (Commission Implementing Regulation (EU), 2019).

As a member of the EU, Sweden is required to keep a register of present fee collectors in the country, where a fee collector is an authority, company or other organization that is responsible for levying tolls for vehicle traffic in an EETS region. For Sweden, only one toll system is registered for this and that is the toll system at the Öresund Bridge that connects Sweden with Denmark.

Technical functionalities for each ERS-technology

In Table 9, technical functionalities are described for respectively ERS technology. The information is mainly based on interviews with ERS-suppliers, complemented by information from the document Commission implementing regulation (EU) 2020/204.

Table 9. Technical capabilities for energy measurement and billing.

Technology	**Energy measurement and billing**
Siemens	For Siemens, energy measurement takes place in the vehicle. There is however also energy measurement in the transformer station connected to the electric road system that can measure the total electricity consumption on a stretch (Commission Implementing Regulation (EU), 2019). According to interviews with Siemens, energy measurement units have been installed in the field trial vehicles on the German public test sites. Proven energy measurement components are used, identical with those in charging stations and that are used for payment processes in other applications. As the measurement units are in the trucks (at the user side), the usage and certification of the systems is easier than in other applications according to Siemens. Hence, they are in discussions with the energy regulators to ensure that the system fits to the requirements and certified according to European measurement laws as well. Siemens has no intention to develop a solution that do not require vehicles to be equipped with the meters. The metering at the infrastructure side is considered as verification measurement and for statistics only according to the supplier. The On-Board Unit (OBU) will communicate with the Back office to provide data for the energy consumption per vehicle. The system relies on satellite data (GNSS) and GPS positioning of the vehicle. The used OBU and Back-office system are those used in tolling applications.

Evias	Measurement of electricity transmission can take place either in the vehicle or in the electric road facility. The measurement of data is preferred to take place in the vehicle and then sent directly via the GSM network to the electric road system. However, there is also a measurement in the electric road system, but the system does not enable to separate vehicles that are on the same rail segment. The data is processed in the electric road system for invoicing and sending the documentation to the party who is to invoice for the use (Commission Implementing Regulation (EU), 2019) . The energy measurement of the substation at the eRoadArlanda was performed by Vattenfall with their conventional system. In addition to this, Evias did add several energy measurement units to measure how the energy was distributed between the substation and the truck (through the rail section) as well as additional units in the vehicle that then sent back the data with GSM. In a commercial system, so many units would not be required. Evias is currently waiting on more specific information regarding in what interface the energy should be measured and based on this they can decide on how the system should be designed in the end. For billing and payment solutions, Evias have begun to develop an open API (Application Programming Interface) to support sharing relevant information from their system to the party who is to invoice for the use of the ERS. This is currently in a very early development phase and hence no information of a potential system design has been observed.
Elonroad	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. The data from energy measurement and other sensors are collected in the cloud service Elonroad Cloud, which also functions as an intermediate software from which data is compiled and provided to an external system when needed. Among other things, there is the possibility of using the open and standardized protocol OCPP to provide access to transaction data (Commission Implementing Regulation (EU), 2019). OCPP (Open Charge Point Protocol) is application protocol for communication between Electric vehicle (EV), charging stations and a central management system. This is also known as a charging station network, similar to 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. The provider needs to activate each end customer in the cloud service via administrative interfaces or APIs. Data is stored encrypted in both the electric road system and vehicles and reported to the central cloud service. From there, it is made available as needed via APIs or other interfaces (Commission Implementing Regulation (EU), 2019). In the public test track in Lund, both energy measurement in the ERS and the vehicles are being tested. As Elonroad has their switches incorporated in the rails, energy consumption in the ERS is measured on each switch and then summed up per vehicle. The ERS system also uses (4G/5G) to communicate with the vehicles to enable sending data back to the system

	(e.g. energy consumption). In addition to this, 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. The system can also recognize if two vehicles use the same vehicle ID for charging, and then reject access to the ERS. As the segments are only one meters long, energy consumption per vehicle can be separated even though the vehicles are close to each other on the ERS. A central computer is used to collect the data from the ERS and the vehicles, which then converts it to a documentation for billing and payment in the could server (Elonroad Cloud).
Electreon	The measurement for charging takes place both in the vehicle and at the control unit that controls and supplies the electric road with electricity. The basis for debiting is sent encrypted for storage in an appropriate way (not defined yet). Data storage and design of payment systems depend on the design of the fee system (Commission Implementing Regulation (EU), 2019). At the public test track Smartroad Gotland, energy measurement is done both in the road and on the vehicles. Today, the system measures this data from point to point, but Electreon is currently developing a system to move all this data into a cloud-solution for easier access and allocation of data. Enabling shared data in a cloud-solution is the first step towards a billing and payment solution according to Electreon. As their system already collects the data for identification and energy consumption per vehicle, Electreon do not see the process of providing an external supplier with such data as a huge challenge. Electreon is currently certifying itself in payment solutions in Germany, no similar activity has been noticed for Sweden.

From Table 9, it can be concluded that for the Siemens and Evias technology, energy measurement for billing is limited to only take place in the vehicles, as energy consumption per vehicle cannot be separated once they are on the same rail segment or under the same overhead line. Elonroad and Electreon supports energy measurement in either the vehicles or in the ERS facility. All technologies are designed to enable encrypted data storage and then send the data to the party who is to invoice for the use of the ERS. It is important to point out that these different functionalities of the ERS, including both energy measurement and access, result in different demands on the underlying systems.

Insights from the government investigation on ERS

This section summarizes the main findings that are relevant to this WP from the government inquiry on ERS presented in August 2021 (Elvägsutredningen, 2021). There is no country yet that has introduced regulations specifically designed for deployment and use of ERS. However, the European Commission has proposed a definition of ERS in the context of the proposal of the AFI regulation that is in progress. Work is also underway in standardization for various ERS-technologies, both in Europe and globally.

The inquiry had the assignment to propose regulations for the deployment, operation, and maintenance of ERS in Sweden. According to the inquiry directives, ERS should be a state commitment in the same way as the responsibility for other national infrastructure. The inquiry concludes that the existing road law applies to the context but suggests a clarification that the ERS is a road device. A starting point in the inquiry's directive is that ERS are not under the concession obligation according to the Electricity Act. Hence, in the regulation on exceptions from requirements on network concessions (or the IKN-regulation), ERS are excepted from requirements for concession. The regulation was changed as of January 1, 2022.

The inquiry was assigned to propose a regulation for the use of ERS, including user charges. Accordingly, a new law on conditions for ERS was suggested. The law proposal contains provisions on charges and other conditions for access to an electric road that constitutes a public road, and for which the state is the road operator. The proposed responsibilities of different actors are illustrated in Figure 8 below.

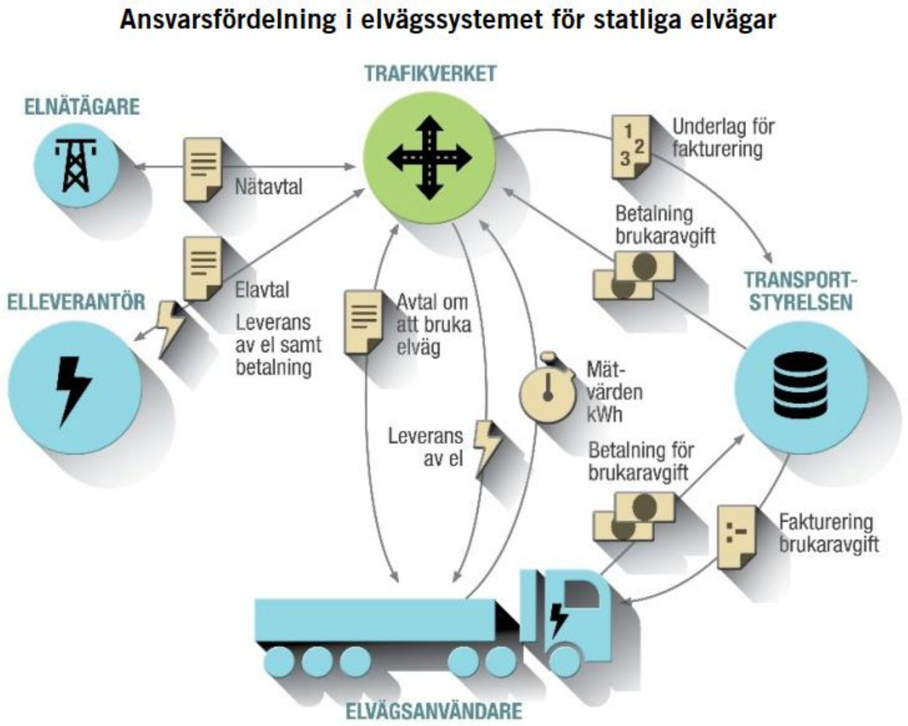


Figure 8. The proposal on division of responsibilities in a public ERS-system made by the government inquiry (Elvägsutredningen, 2021).

The proposed division of responsibilities means that the Swedish Transport Administration (Trafikverket) would be the party responsible for the provision of state-owned ERS, both in terms of infrastructure and supply of electricity to vehicles using the ERS. The Swedish Transport Agency (Transportstyrelsen) would be responsible for debiting the user charge and proposed to do this in a similar way as when the authority handles infrastructure charges today. There are however some differences, for example the need for data on measured consumed energy, that are stored at the Swedish Transport Administration. This information will therefore have to be shared with the Swedish Transport Authority so they can send the bills to the users of the ERS.

The inquiry proposed that a user charge should be charged for the use of the ERS and should cover:

1. the costs of operation and maintenance of the electric road facility,
2. the costs of operation and maintenance of the associated user authorization and charging systems,
3. the increased road maintenance costs caused by the electric road facility, and
4. the payment for electricity consumed

The method of calculating the user charges is proposed to be distributed based on the consumed kWh. The level of user charge should also be calculated based on the assessment of the traffic volume over a longer period, as the number of users is expected to increase gradually.

The following data is likely to be needed for billing:

- Vehicle identity
- Time
- Coordinate (alternatively facility ID or other location)
- Energy consumption

Technical functional requirements on both vehicle equipment and the ERS facility may relate to the standards that are currently being developed. The vehicle owner will be responsible for the equipment in the vehicles and the Swedish Transport Authority will be responsible for the functional requirements. For the vehicles, this might have an impact on components such as:

- Vehicle pick-up unit
- Unit that manages access
- Energy measurement unit

And for the ERS facility:

- Energy metering
- User authorization / access control
- Power control

There may also be requirements for power electronics, with harmonized standards that have a holistic perspective on electric road technology, so that the vehicle's internal equipment and the electric road system do not cause EMC disturbances. Also, electrical safety could be included.

Payment intermediaries according to EETS

The government inquiry also identifies EETS as a potential future model that could replace the Swedish Transport Agency's role as responsible for debiting. In the long run, it could be a European solution for a contact point for charging electric road users, as well as for other tolls, regardless of nationality and where in Europe the electric road user is located. A prerequisite is that the EETS directive is adapted to also include charges for electric roads. An advantage of payment intermediaries according to EETS is that it facilitates international transport.

In Sweden, there is currently no established system with payment intermediaries according to EETS. The EETS directive was implemented in Swedish law in 2021. If a larger ERS-network will be delayed within the EU, the government inquiry suggests taking into consideration whether electric roads should be covered by the EETS directive. Moreover, cross-border interoperability is proposed to be encouraged and hence the inquiry is positive about including user charges for electricity in the EETS system, primarily in the longer term though. In short term, this option is deemed by the inquiry to result in an excessive administrative and financial burden for Sweden.

WP 3 Corridor analysis and economic impacts

WP 3.1 Corridor Analysis

An ERS can be understood as a coherent system that provides benefits for haulage companies. There are considerable arguments for government intervention and financing, not least due to the possibility of positive network effects and the risks associated with a natural monopoly. It is likely that the initial phase will be characterized by relatively low profitability because (1) few actors will utilize it until it reaches a critical size and (2) the market for vehicles with ERS-components will likely take time to mature. WP 3.1 considers the type of potential corridors that may be ripe for establishing an ERS and the type of freight that might utilize it. The task is to analyse the following prerequisites for implementation:

- Identification of possible routes along trans-European network for transport (TEN-T) corridors
- Traffic volumes
- Type of commodities and other transport characteristics on an aggregated level.

The aim of WP 3.1 is to build knowledge around traffic and transport: i.e., the composition of goods being transported, how they move and what types of forces may affect them. The objective is to gain insight into the potential for a rollout of ERS in Sweden, including extensions southward toward continental Europe.

Transport demand is often described as a *derived demand*, both for passengers and freight. This means that the demand for transport is derived from other activities – which are often spatially differentiated – thus creating a need to bridge distances. For example, firms and households in Sweden demand goods that are produced elsewhere, creating a demand for freight. Likewise, firms and households in other countries demand goods produced in Sweden.

Two key prerequisites for constructing an ERS corridor are (1) the amount of goods being transported and (2) the number of heavy-duty vehicles (HDV) in the corridor. This, in turn, suggests a need for more information about the kind of commodities being transported by road and how far they travel. Dynamic charging is particularly useful when HDVs travel long distances; in contrast, stationary charging has an advantage for HDVs focusing on local or regional haulage.

This section starts with a summary of the work and findings in the previous CollERS project and then presents the TEN-T corridor with relevance for a Swedish ERS rollout. Next, we provide data on overall traffic volumes (vehicle kilometres, tonne kilometres by different transport modes, etc) and include a presentation of the amount of goods (in tonnes) transported by commodity group, mode of transport and distance travelled.[11] Finally, we discuss costs, which provides a link to WP 3.2.

Previous corridor study within CollERS

A previous report (CollERS 1) analysed the corridor between Hamburg in Germany and Helsingborg in Sweden in terms of four aspects: technical, environmental, economic, and political (Jöhrens, et al., 2021). The feasibility criteria are mainly based on observations from transport flows and vehicle usage patterns along the corridor.

According to the authors, the analysis contributes primarily in terms of a methodological approach, but the theoretical framework has also been exemplified through an analysis of the potential corridor in

---

[11] Note that there are three statistics presented in this chapter: vehicle kilometres, tonnage and tonne kilometres. The first represents the total number of kilometres covered by vehicles, the second captures the tonnes being carried; and the third combines the first two statistics in terms of both distance and weight travelled.

Denmark. Based on three transport corridor alternatives through Denmark, the route selected for further assessment runs from Hamburg, via Lübeck, crossing the Fehmarn Belt between Puttgarden and Rødby, and across Öresund. The starting and ending points (Helsingborg and Hamburg) were selected due to their importance as motorway junctions, with traffic spreading in various directions.

The exact route chosen was driven by the importance of the Fehmarn Belt, which offers ferry transport. When the future Fehmarn Belt Fixed Link is complete, this route choice will likely become even more important. The corridor is 424 km long. The analysis included data from official statistics in Germany, Denmark, and Sweden, as well as data from ferry lines and bridges. Detailed information about data sources is provided in the report (Jöhrens, et al., 2021).

Technical Aspects

- It is estimated that 45% of the traffic with heavy-duty vehicles (HDV) in the corridor will involve trips with pre- and post-haul distances of less than 250 km. 22% of these trips will likely involve mileage on the ERS. The analysis is limited to vehicles of at least 12 tonnes (gross) and 3 axles. The analysis concludes that there is a considerable share of routes on the corridor suitable for ERS, but the relative mileage is rather low.
- The necessary reinforcement of existing high voltage grids for electric power supply for ERS seems unlikely.
- The standardization of ERS is not mature, which complicates interoperability.

Environmental Aspects

- The expected CO_2-emissions from truck traffic along the corridor can be significantly reduced if electric trucks are powered by the national electricity mixes expected for the year 2030. Reductions will be even more significant if electricity is powered by renewable energy sources.
- Positive impacts on air quality from an ERS is expected to be limited.
- Positive impacts on noise reduction from an ERS are unlikely for a free-flowing motorway, but current noise impacts may be dampened in congested areas.

Economic Aspects

- Under current conditions, the corridor is not expected to be economically feasible. Electrifying only some parts could be an option.
- In the first phase of introducing the system public grants will be required in order to support the manufacture of ERS-capable trucks. But after developing the corridor itself, it is likely that large-scale truck production due to a reduction in production costs and the subsequent scaling-up of ERS technology.

Political Aspects

- Collaboration on a corridor project could lead to strategic coordination between participating countries and thus raise awareness about an ERS within the EU.
- Establishment of an ERS corridor system is likely to spread knowledge about the technology due to increased visibility and exposure, not least through media coverage.

Jöhrens et al. (2021) concluded that electrifying the corridor will require an exceptional effort from a variety of stakeholders and industrial sectors. The payoff, however, is the possibility to decarbonize heavy-duty transportation for the entire region. There are several factors determining future uptake of the technology, not least whether or not the logistics sector chooses to adopt it, which is mainly driven by economic factors. Other factors determining future uptake include the speed at which competing fossil-free alternatives are developed, such as pure battery trucks and fuel cell trucks.

There may be other co-benefits associated with developing an ERS (see CollERS 1 report), including the possibility of stimulating a larger market for trucks with ERS-components. Expanding the proposed corridor may also act as a catalyst for further investment in ERS – both in these countries as well as other countries.

The total demand for transport in Sweden is increasing but the modal split is relatively unchanged over time. Trucks registered in Sweden dominate the domestic transport market while foreign trucks do most of the transport to and from Sweden (and their share is growing). In general, both freight volume and the number of transports executed by road freight transport, are increasing. This is particularly evident for short and medium distances.

Potential corridors for ERS

The trans-European transport network (TEN-T)

As noted in the chapter "WP 2.5 Standardization and interoperability" in this report, the European Union has an ambition to provide a seamless, trans-European transport network (TEN-T). This network will include two layers: a *core network* (to be completed by 2030) and a *comprehensive network* (to be completed by 2050). The core network links the most important nodes in the European Union. An example is the Scandinavian–Mediterranean (or Scan-Med) which is shown in pink in Figure 9.

Figure 9: Map showing part of the TEN-T. The map shows roads and ports included in the corridors. Source: (European Commission, 2021)

The current Scan-Med corridor in Sweden includes the entire E4 (from Helsingborg via Stockholm to Haparanda) and the E6 (from Trelleborg via Gothenburg to Oslo). It links Sweden and Denmark via the Öresund fixed link, and continues through Denmark in two ways: to Rødby and across Fehmarn Belt to Hamburg and west towards Jutland and then south to Hamburg. The Scan-Med corridor also includes the ports in Stockholm, Gothenburg, Malmö and Trelleborg. As for road freight, both Malmö and Trelleborg have connections to the German ports of Lübeck and Rostock (also included in Scan-Med). On the German side, the corridor links Rostock with Berlin. Note that the ports of Helsingborg in Sweden and Helsingør and Gedser in Denmark are not included in the corridor.

The Scan-Med corridor offers benefits well beyond Sweden (Trafikanalys, 2016), because it connects via ferries to the Baltics and Poland which bring in several other corridors: the North Sea-Baltic corridor (red in Figure 8), the Baltic – Adriatic corridor (blue) and the Orient/East – Med corridor (brown). In a possible future scenario where the transport routes turn more to the east, the northern parts of these corridors are of particular interest from a Swedish perspective (Trafikanalys, 2016).

A possible stepwise roll-out of ERS

The Swedish Transport Administration was tasked by the Swedish government to plan for the expansion of an ERS along the busiest traffic routes in Sweden (Trafikverket, 2021). The government established two targets: first that the expansion should be economically viable and second, that they contribute to reducing greenhouse gas emissions. The Swedish Transport Administration suggested that the expansion of an ERS be a stepwise roll-out. The main reason is that technological development of the various system options is very rapid and may change over time.

The orientation report for (Inriktningsunderlag) stressed that the above-mentioned sketch would set the ambition for the electrification (Trafikverket, 2020). According to the orientation report, the first permanent ERS in Sweden would be ready by 2023, but according to the proposal for the national transport infrastructure plan this project is to be finished by 2026 (Trafikverket, 2021). After this pilot project, the plan for ERS is to focus on the main routes connecting the so-called triangle “Stockholm-Gothenburg-Malmö,” which contains not only the busiest roads in the country, but also leads to some of Sweden’s most important ports and terminals. These routes could also enable international connections and “electric road corridors” to other parts of Europe.

The proposed first stage is expansion within the Malmö-Stockholm route, along the main part of the 610-kilometre stretch along motorway E4. A significant share of the traffic consists of long-haul transport, which would benefit from not having to stop and recharge batteries. The proposed second stage would include the Malmö-Gothenburg route along motorway E6 (approximately 300 kilometres). Lastly, the proposed third stage would include Gothenburg-Stockholm along motorways E20 (from Gothenburg to Örebro) and E18 (from Örebro to Stockholm), which stretches 480 kilometres and represents a busy freight route. The pilot project mentioned above constitutes part of the third stage.

The proposal for the national infrastructure claimed, however, that the ambition for ERS is lower than the sketch described above. It is predominantly the development of batteries that reduced the ambition. Also, long lead times makes further expansion until 2026 unlikely. The strategy is currently to revise the above-mentioned expansion proposal and identify suitable stretches of about 200 to 300 kilometres (Trafikverket, 2021). Still, when further, concrete, plans are decided upon, parts of the “triangle” is likely to be appropriate for expansion.

Principal routes for freight transport in Sweden

Sweden's freight transport is concentrated to six principal routes, which cover two-thirds of freight transport by volume (see also Figure 10 and Transport Analysis (2016)). These include:

1. A north-south land-based route going through Luleå – Greater Stockholm – Malmö/Trelleborg, with an extension to the European continent
2. Shipping in the Baltic Sea
3. The transport network between Gothenburg and Stockholm (motorways E20, E4, national motorway 40, and the railway *Västra Stambanan*), including extensions west from Gothenburg and east from Stockholm
4. The transport network stretching from the northern parts of Sweden via Hallsberg (a rail hub) to Gothenburg (including the railway *Bergslagsbanan*, E18, and the national motorway 67)
5. A route from Norway via Svinesund – Gothenburg – Malmö – Trelleborg and the railway *Västkustbanan*
6. The railway *Malmbanan* with shipping connections in Narvik, Norway.

Figure 10 shows Sweden's most important links for freight transport. The largest ports in terms of tonnage are Gothenburg, Brofjorden (on the west coast), Helsingborg, Malmö, Trelleborg, Stockholm and Luleå. Gothenburg is especially important, being one of the top twenty largest ports in Europe. The transport flows to and from Gothenburg, which makes vital land-based infrastructure like motorway E20 and the trunk railway *Västra Stambanan*. The motorway E4 between Norrköping and Jönköping combined with the national motorway 40 between Jönköping and Gothenburg, also constitute essential routes for the port of Gothenburg. According to a model simulation in 2010, 40 percent of the tonnage transported by road relies on these routes, despite the fact that they constitute only 3 percent of the total road network in Sweden (Vierth, Mellin, Hylén, & Karlsson, 2012).

The cargo between Denmark and Gothenburg consists of oil imports and petrochemical products. Moreover, a part of the transport flow between the Swedish west coast and the southwestern part of Norway goes via the port of Gothenburg. This is also true for transport to and from the eastern parts of Europe, especially Russia. Trade with Russia has declined sharply due to the war in Ukraine (Kommerskollegium, 2022).

Important international road connections for freight transport include: the Öresund fixed link (to Denmark); the Svinesund bridge; E18 at Töcksfors; E10 at Riksgränsen (to Norway); and E4 at Haparanda, with connection to Torneå, Finland. The Öresund fixed link also provides an important rail connection for goods to and from Denmark, Germany, and the rest of the European continent. In addition, there are train ferries, (and truck ferries), going between Trelleborg and Sassnitz. Ferries also operate on the route between Ystad and Świnoujście (Swinemünde) in Poland.

Overview of freight transport

Freight transport is summarized by the statistics authority Transport Analysis in the “Commodity flow survey” (*Varuflödesundersökningen*) (Trafikanalys, 2016). In 2014, 630 million tonnes of goods were transported. Most of the domestic freight went by road, whereas a majority of the international freight went by sea. In 2014, roads made up about 65 % of all freight (in terms of tonnage). Roads also dominated most commodities, the exceptions being coal and lignite, coke and refined petroleum products, and unidentifiable goods, which go by sea.

Consumption is primarily concentrated in the densely populated areas in the southern parts of the country, while production is primarily concentrated in the northern parts, Västra Götaland and the Norrland coast. Basic industry constitutes a large part of freight transport, with metal ores and other mining and quarrying products being the largest commodity group in terms of tonnage.

The dominant export market for Sweden is Europe, with Germany, the United Kingdom, the Netherlands, and the neighboring Nordic countries being the largest partners. Imports come largely from Norway, Finland, Germany, and Russia. In 2016, outgoing consignments from Sweden destined for Germany constituted 14,8 percent of the total tonnage to all countries, and 12,0 percent in terms of invoice value. Incoming consignments from Germany to Sweden constituted 6,2 percent of the total tonnage from all countries, and 15,2 percent in terms of invoice value. Norway is also an important market in terms of both exports and imports. Figure 10 displays the flow of goods to, from, and within Sweden in terms of tonnage.

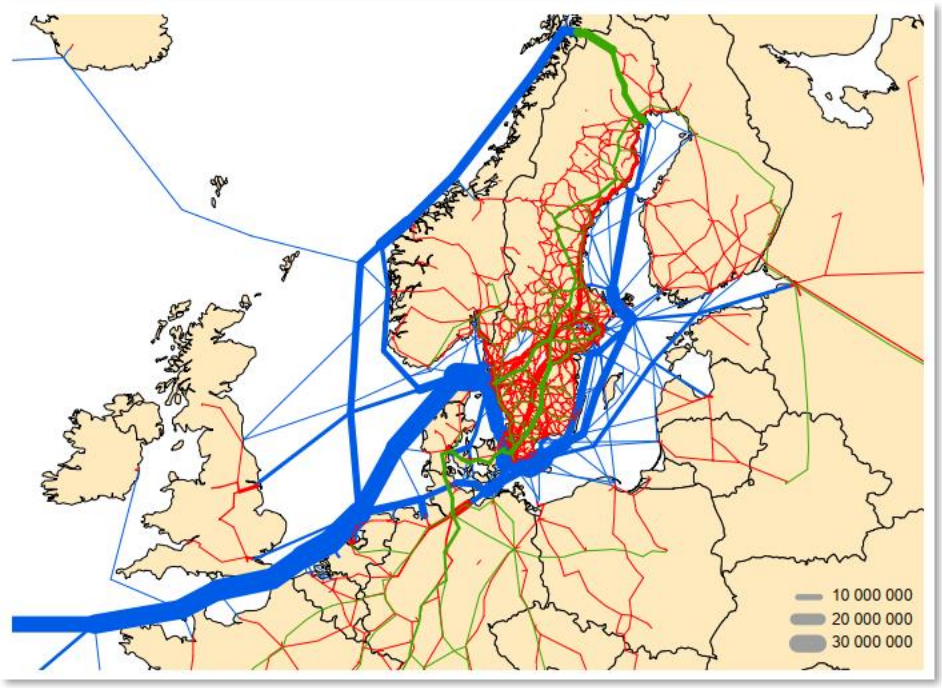


Figure 10: Freight transport flows with shipping (blue), rail (green) and road (red). Based on data from 2006. Source: (Trafikanalys, 2016)

Road freight dominates for shorter distances (rail and shipping are essentially non-existent). Only 8 percent of the road freight travelled longer than 300 kilometres. Thus, the potential for modal change to rail or sea is largest for longer distances (Trafikanalys, 2016). However, since the modal share for shipping is already large in this segment and since railways are limited due to capacity constraints and competition for track slots with passenger trains, road transport offers an attractive option. Road transport in particular offers a flexibility that is unmatched by shipping and rail. Road dominates domestic transport (around 66–68 %), while shipping dominates import/export (around 55–65 %). Railway and shipping tend to be competitive on longer distances, e.g., a minimum of 300 to 400 kilometres is generally required for rail to be a viable option (Trafikanalys, 2022). More on the substitution between transport modes in the subchapter “What determines the choice of transport mode?”.

Freight and modal split

The size and type of freight transport flows are, to a large extent, determined by the location of industrial production. The demand for shipping flows rests on demand for oil and petrochemicals as well as for iron ore. The demand for rail transport likewise depends on the demand for iron ore and steel but, in the south of Sweden, depends on the demand for highly processed goods. Road transport is concentrated on the motorways and dominates food products, beverages, textiles and furniture.

Maps, such as Figure 10, that display total transported volumes (by type) illustrate important links and nodes in the network where freight flows converge. The main links in Sweden consist of shipping routes from the west to ports along the Swedish west coast, via motorways. These links also include an international railway to Öresund and Gothenburg. The railway eventually leads up along the Swedish east coast to the northern parts of the country. There are, however, significant geographical differences in infrastructure use across various product groups.

A large majority of domestically transported goods are transported on road, regardless of commodity. Road transport is most common in southern Sweden and generally concentrated on the motorways between Stockholm, Gothenburg, and Malmö. The dominant commodities are agricultural products and food, forest products, petrochemical products, and material for construction. Other commodities, such as wood materials, crude oil, and petrochemical products, are generally transported by a combination of road and sea. This road-and-sea combination is particularly relevant for commodity groups steel, metal goods, and highly processed goods. When it comes to road transit volumes, the main volume goes between Norway and continental Europe via the Öresund fixed link. Another important transit route is the motorway E18 (Stockholm – Oslo) which, combined with ferries, transports goods between Norway and Finland. Thus, a substantial part of the utilization of the road network is directly attributable to domestic volumes. Shipping is only used to a small extent for domestic transport.

Figure 11 displays the tonne-kilometres for each of the five transport modes. Although caution should be used when comparing these figures due to different calculation methods, they nonetheless show that road transport far exceeds both rail and sea.

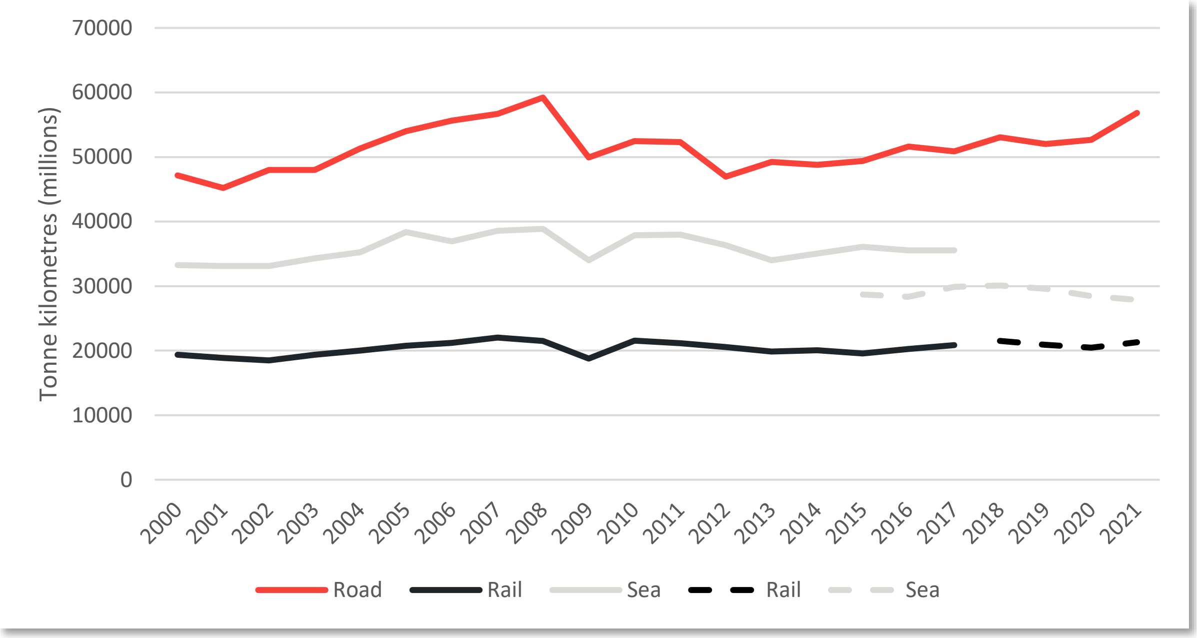


Figure 11: Tonne-kilometres transported by road, rail and sea respectively. The comparison between the modes should be made with a grain of salt due to different models for calculating the different modes. Source: (Trafikanalys, 2022).

About 50 percent of all freight is transported on roads (Trafikanalys, 2022) and this figure has been relatively stable over the period 2000-2018, deviating between 45 to 52 percent (Jussila Hammes, 2020). The modal share per commodity group between Sweden and the European continent is dominated by road (Figure 12), according to Intraplan (2014), the source for the corridor study in CollERS 1). In general, processed goods seem to be transported by road, while raw materials and low-processed goods are, to a degree, also transported by other transport means. For example, only 3% of the highly processed product group *Transport Equipment and Machinery* is consigned by rail, to be compared with the 41% of the product group *Metals*. These numbers are in sharp contrast to the numbers seen elsewhere where shipping dominates international freight.

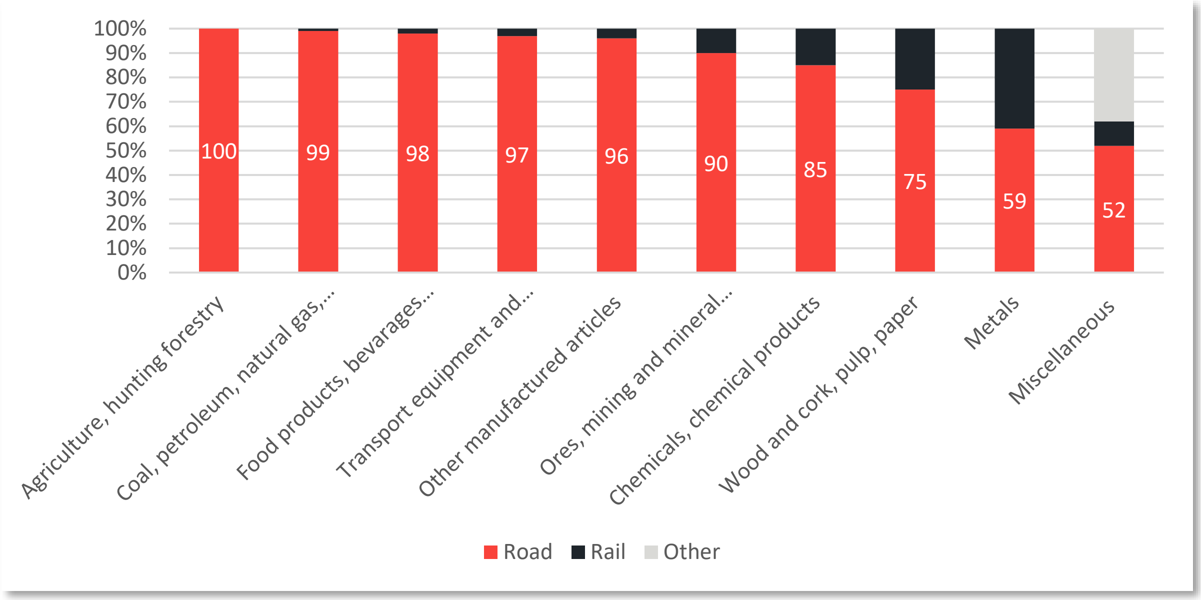


Figure 12 Export tonnage in percent, Scandinavia to the continent, by transport mode. Source: (Intraplan, 2014)

An alternative data source for this statistic comes from Transport Analysis and contains figures for modal share of domestic transport in Sweden (Trafikanalys, 2022). Figure 13Figure 13 indicates road transport dominates several commodity groups, while others are dominated by rail and shipping. The commodity groups are indexed to save space (see indices in Table 10).

Commodity groups 3, 6, 8, 10, 12, and 14, are generally transported via rail within Sweden. These commodities consist of metal ores and other mining and quarrying products. With a few exceptions, most of the commodity groups transported by rail consist of raw materials or low processed products.

Agricultural products involve less processing but are nevertheless transported entirely by road, according to this data. The geographic availability of transport mode is crucial here because farmers are less flexible in transport choice (farming is spread out across the landscape, rather than along railway lines or near ports). Groups 2, 3, 7, 9, 20 are, however, partly transported by sea as heavy cargo. Transport by sea has its largest shares among commodities coal and lignite, crude petroleum and natural gas, metal ores and other mining and quarrying products, coke and refined petroleum products, and non-metallic mineral products.

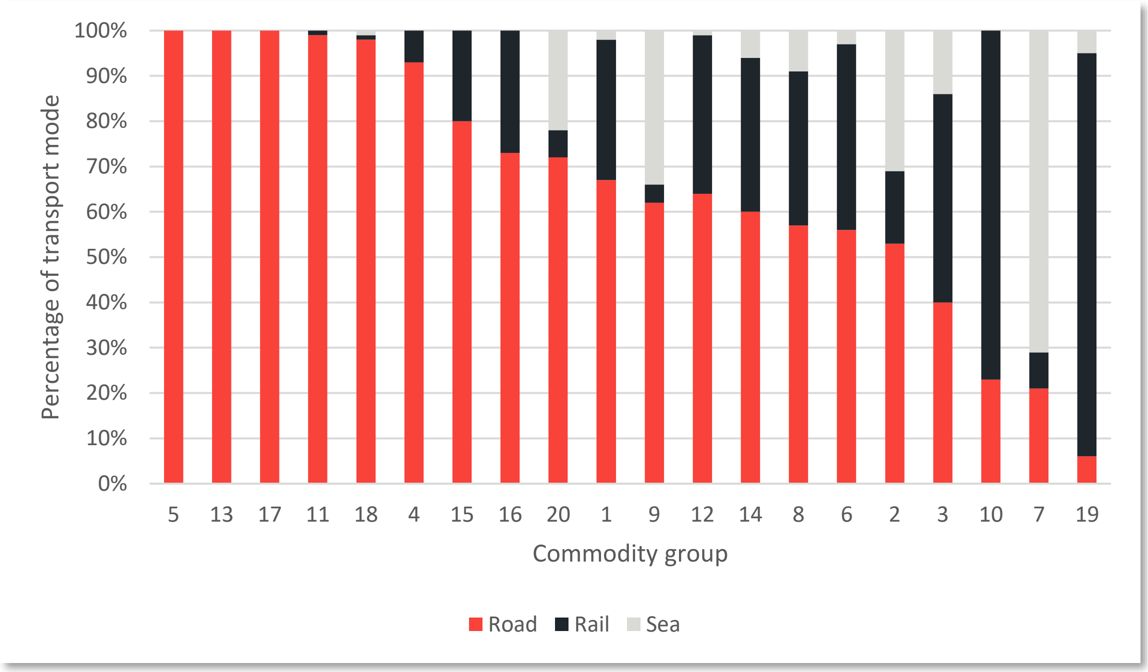


Figure 13 Tonne-kilometres in percent by transport type for domestic transport in Sweden. Commodity groups are defined in Table 10. Source: (Trafikanalys, 2022)

The commodity groups are defined in Table 10 below to save space. Note that figures below also refer to this table.

Table 10. Commodity groups descriptions and indices

Index	Commodity group
1	Products of agriculture, hunting, and forestry; fish and other fishing products
2	Coal and lignite; crude petroleum and natural gas
3	Metal ores and other mining and quarrying products; peat; uranium and thorium
4	Food products, beverages and tobacco
5	Textiles and textile products; leather and leather products
6	Wood and products of wood and cork (except furniture); articles of straw and plaiting materials; pulp, paper and paper products; printed matter and recorded media
7	Coke and refined petroleum products
8	Chemicals, chemical products, and man-made fibers; rubber and plastic products; nuclear fuel
9	Other non-metallic mineral products
10	Basic metals; fabricated metal products, except machinery and equipment
11	Machinery and equipment
12	Transport equipment
13	Furniture; other manufactured goods n.e.c.
14	Secondary raw materials; municipal wastes and other wastes
15	Mail, parcels
16	Equipment and material utilized in the transport of goods
17	Goods moved in the course of household and office removals; baggage and articles accompanying travellers; motor vehicles being moved for repair; other non market goods n.e.c.
18	Grouped goods: a mixture of types of goods which are transported together
19	Unidentifiable goods: goods which for any reason cannot be identified and therefore cannot be assigned to groups 01-16
20	Other goods n.e.c.

Swedish import and export flows

The flow of imports to Sweden via the Baltic Sea is larger than the corresponding exports. However, the opposite applies to shipping in Kattegatt, Skagerak and the North Sea. On the railway *Malmbanan* (between Luleå and Narvik, Norway), more freight is exported than is imported. The railway export flows from the port of Gothenburg are also larger than the import flows. However, the import flows via railway on the Öresund Bridge are larger than the export flows. For road transports along this route, the volumes are slightly larger for exports than for imports.

In terms of road freight, one can have a look at port statistics and statistics from the Öresund fixed link (Figure 14).[12] As for the border crossings of roll-on/roll-off units (abbreviated "RoRo" and includes trailers, tractors and containers on trucks), Trelleborg constitutes the largest port, with Gothenburg and Stockholm second and third, respectively. Figure 14 does not include all ports in Sweden, rather it covers the main ports and all ports in the south. Note, however, that the ports of Skåne (Trelleborg, Helsingborg, Ystad and Malmö) and Öresund together constitute two-thirds of the units passing through these places.

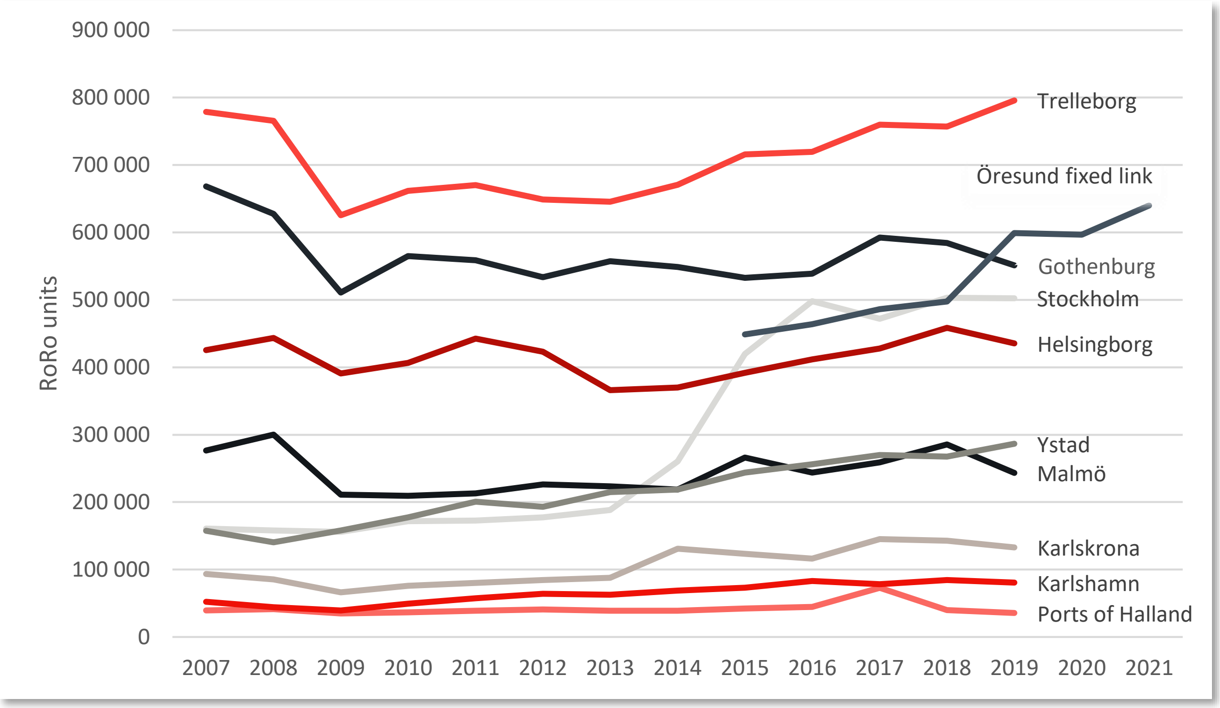


Figure 14: RoRo units by port in Sweden and freight vehicles longer than six meters going across Öresund. RoRo is an acronym for Roll-on/Roll-off, i.e freight that is rolling on and off a ferry, for example by truck.

The data on road transport crossings does not provide insight into whether the transported goods are arriving or departing Sweden. It is noteworthy that several ports presented in Figure 14 (e.g., Helsingborg and Ystad), are not within the TEN-T network.

Transports and commodity flow between Sweden and Germany

This subchapter presents data on the flow of goods between Sweden and Germany. The flow is described in terms of modal split, commodity group and briefly in terms of NUTS II regions in Sweden.[13] The modal split provides important insight in order to understand the potential for an ERS between Sweden and Germany. The data also help to triangulate and understand the connection between transport mode, commodity type and potential origin/destination in Sweden.

Transport modes of freight Sweden to Germany

Beginning with transport mode in the direction from Sweden to Germany, the combination of rail and shipping (indicated "JS" in Figure 15) supports about half of the total tonnes transported. The other common modes are shipping (S) and road (V), each of which contribute with about 2 million tonnes per year.

---

[12] See Port of Gothenburg (2022) and Öresundsbron (2022).

[13] NUTS is an acronym for Nomenclature des Unités Territoriales Statistiques.

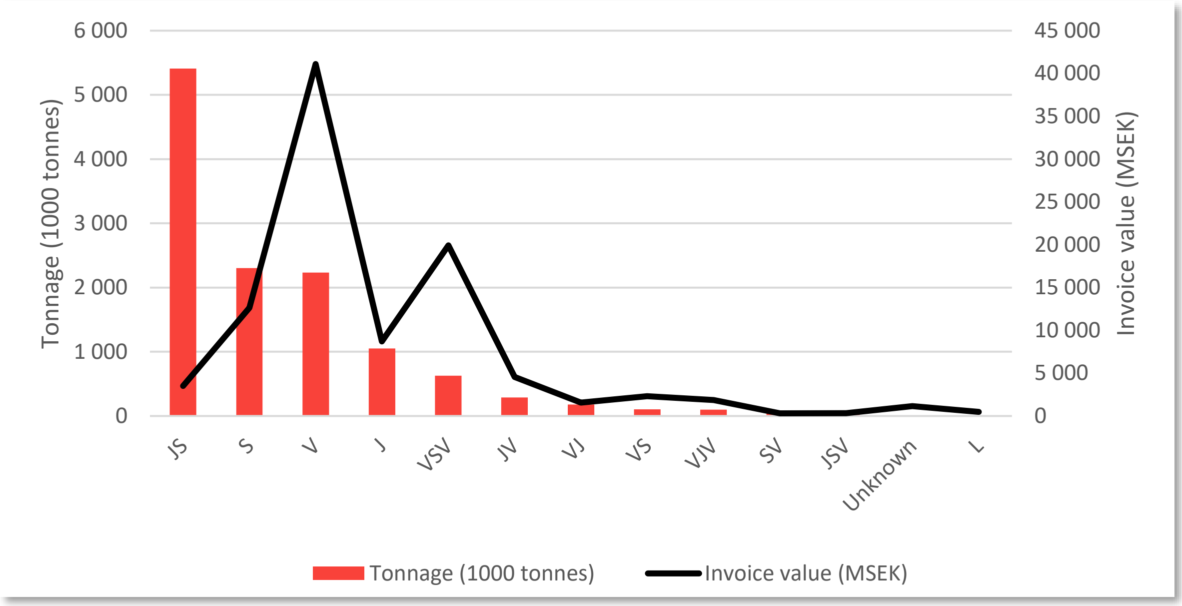


Figure 15: Tonnage and Invoice values in terms of transport modes (direction Sweden to Germany), in 2014. J is rail, S is shipping, V is road and L is air, the other abbreviations are combinations of the previous four. Source: (Trafikanalys, 2016)

Transport by sea (“S” in Figure 15) accounts for 19 % of the total tonnage and roads (“V”) account for 18 %. The significance of the rail and shipping combination is linked to the fact that Sweden exports a large amount of metal ores and other mining products (see more details below). Interestingly, the invoice value of these transports paints a different picture than the tonnage. The invoice value of road transport is by far the largest at MSEK 41 000. The corresponding value of transport by sea is MSEK 13 000.

Commodity group transported Sweden to Germany

The most important commodities transported from Sweden to Germany are divided into 16 groups (defined in Table 10) and the data are displayed in Figure 16. The figure shows that metal ores and other mining products (coded number 3), are the largest measured by weight, and represent approximately half of all weighted transports. In 2014, 6 million tonnes of metal ores were transported (at a value of approximately MSEK 5 000) from Sweden to Germany. The largest commodity group measured in terms of invoice value, however, is wood and products of wood (coded number 6), at MSEK 25 000.

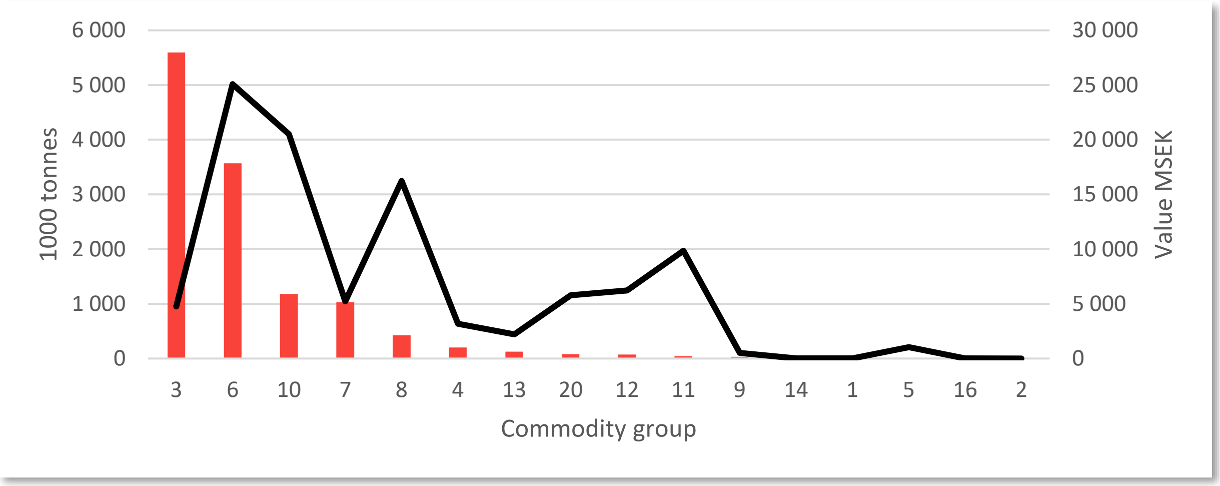


Figure 16 Tonnage and Invoice values in terms of commodity groups (direction Sweden to Germany) in 2014 Source: (Trafikanalys, 2016)

Regional distribution of the freight Sweden to Germany

Statistics about goods transported to Germany, from NUTS II regions within Sweden, show that freight from the northern part of Sweden is by far the largest in terms of tonnes. About 6 million tonnes were consigned in 2014, which corresponds with the numbers for iron ore and other mineral products as seen in Figure 16 as well as the numbers for the combinations of rail and sea transport in Figure 15. The value of this freight was about MSEK 10 300, which is less than the value of the freight from the NUTS II regions in south Sweden. The NUTS II region “SE22”, near Malmö in South Sweden, exported a value of MSEK 18 700 during the same period while region “SE23” (West Sweden around Gothenburg etc) exported a value of MSEK 18 400. The goods transported from the north are very heavy, consisting mostly of metal ores, mining and quarrying products, and wood products. In contrast, goods from the south are generally more processed and of higher value per tonne.

Transport modes of freight Germany to Sweden

Switching perspective to the freight going from Germany to Sweden, the total amount (tonnes) is far lower (Figure 17): only a quarter of the weight that goes from Sweden to Germany. Transport from Germany to Sweden is dominated by both sea transport (coded “S”) and road (coded “V“) with about 1 million tonnes each. However, when it comes to invoiced value of goods, transport by road (“V”) is by far the largest with MSEK 28 900. The corresponding amount for sea is MSEK 4 100, and for rail (”J”) MSEK 950. In between are combinations of various transport modes.

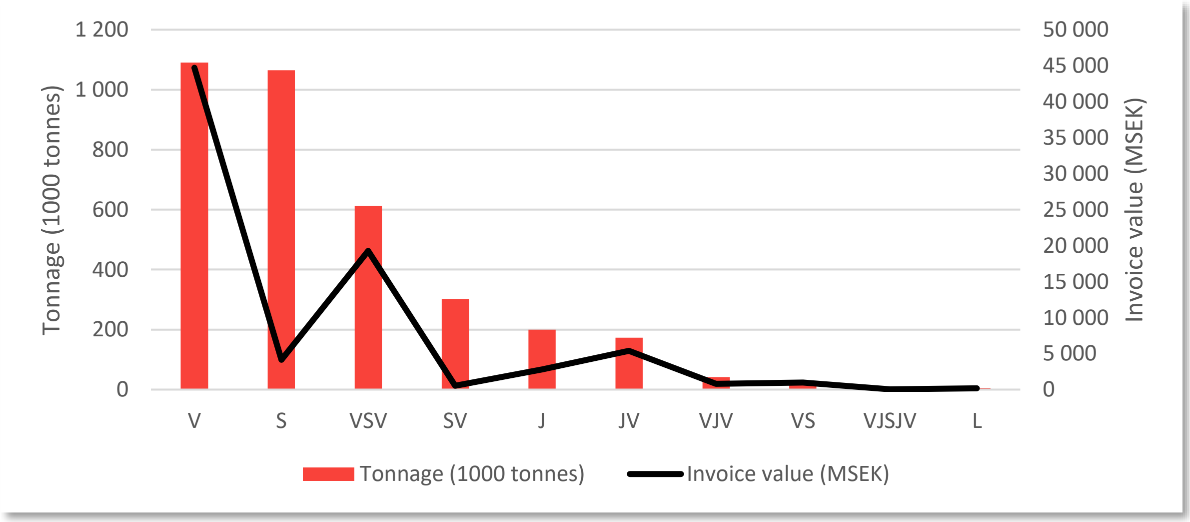


Figure 17 Tonnage and Invoice values in terms of transport modes (direction Germany to Sweden), in 2014. Source: (Trafikanalys, 2016)

Commodity group transported Germany to Sweden

Indications of commodity groups regarding transport from Germany to Sweden are illustrated in Figure 18, which shows that coke and refined petroleum products (coded “7”) are the largest group measured by tonnes, representing a weighted share of about 22 percent of all commodities. The total invoice value is largest for the group transport equipment (“12”), amounting to MSEK 26 800. But this group is only the third largest by weight (a weighted share of 14 percent of all commodities). See Table 10 for commodity indices.

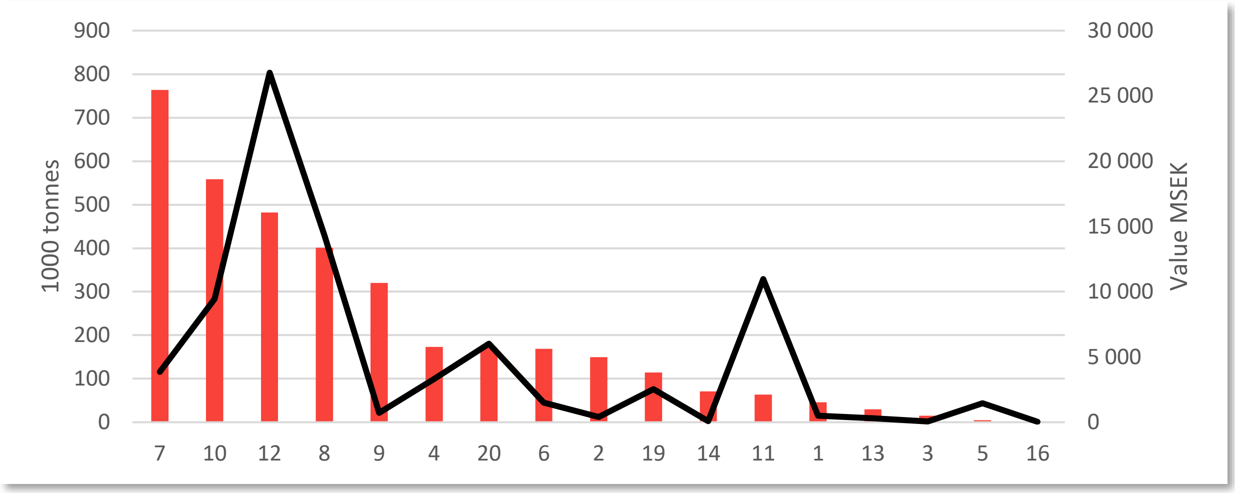


Figure 18: Tonnage and Invoice values in terms of commodity groups (direction Germany to Sweden) in 2014. Source: (Trafikanalys, 2016)

Regional distribution of freight Germany to Sweden

The freight consigned to the western parts of Sweden (around Gothenburg) is the heaviest (1million tonnes), which corresponds to almost one third of all tonnage. The value of these shipments is also the largest (MSEK 23 060). This can be explained by the fact that the port of Gothenburg is the most important in the country and the largest in Scandinavia. Further, the southern parts of Sweden are much more densely populated than the northern parts, which means only a small share of this transport goes to the northern part of the country.

The Swedish transport market: domestic and international

Heavier vehicles dominate in terms of vehicle kilometres

The amount of vehicle kilometres travelled by heavy duty vehicles in Sweden (Figure 19) has increased substantially for the heaviest vehicles (>26 tonnes), but has decreased for both medium and light goods vehicles. The total vehicle kilometres in 2030 in Sweden is estimated to 1 431 and 3 209 million for 40- and 60-tonne vehicles, respectively, according to data from Transport Analysis 2018 and Swedish Transport Administration's freight transport forecast. (Börjesson, Johansson, & Kågeson, 2020). That number is about 16 % more than the (preliminary) figures for 2021 (see Figure 19). The proportion of these vehicle kilometres that could be fueled by ERS depends on the size of the network.

The existing public road network consists of approximately 98 500 kilometres. The bulk of heavy road transport runs on the main road network, which is built to handle heavy loads. The heavy vehicle fleet in Sweden consists of approximately 80 000 vehicles, almost exclusively powered by diesel/bio - diesel. The predominant growth in this vehicle fleet is within the segment of heavy goods vehicles (Trafikanalys, 2022), as shown in Figure 19.

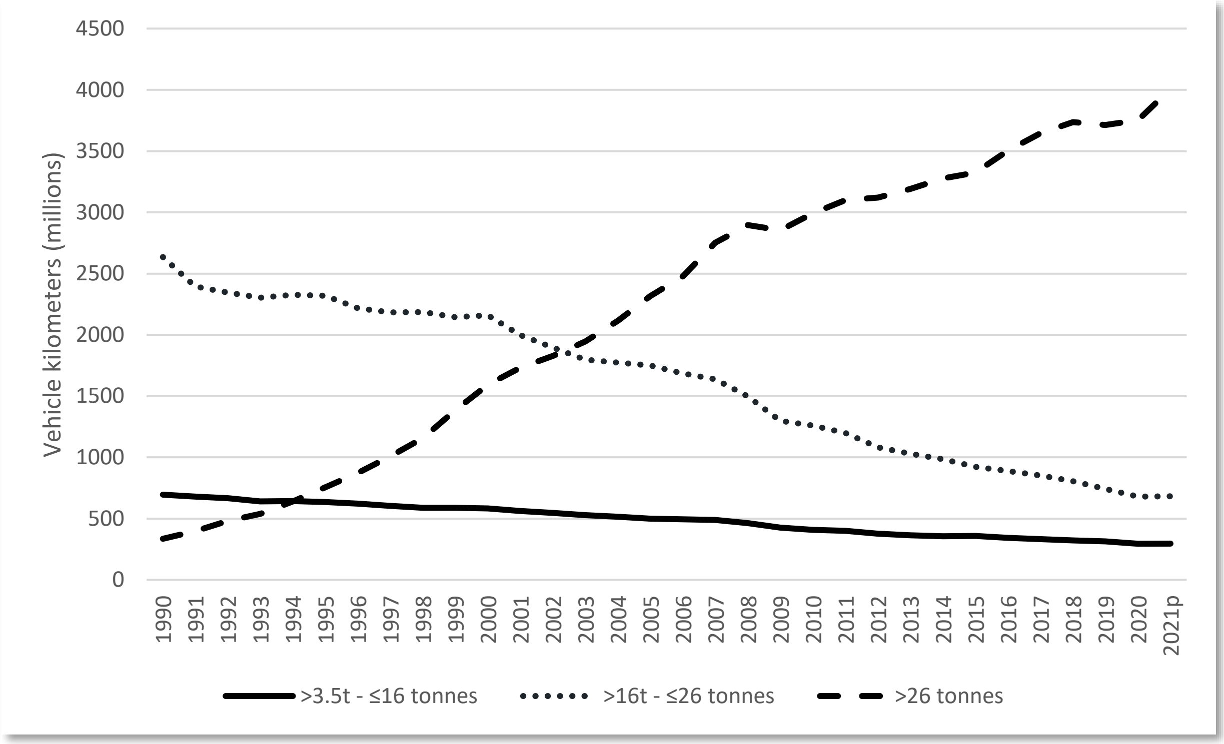


Figure 19: Vehicle kilometres on Swedish roads, by freight vehicle size. The heaviest vehicles have increased substantially since 1990. The figures for 2021 are preliminary. Source: (Trafikanalys, 2022)

A few years ago, the Swedish parliament approved the use of heavier trucks (74 tonnes instead of 64 as a maximum weight), which were designed to support the heaviest vehicles used in the forest and wood industries. In the spring of 2022, the government also considered extending maximum lengths for these vehicles. Today’s limit is 25,25 metres and the government proposed 34,5 metres on certain roads (Regeringen, 2022). The potential for heavier and longer vehicles does not, however, necessarily mean heavier loads since the average load weight today is approximately 17 tons, which is well below the current maximum of 64 tonnes and far below the suggested increased according to Transport Analysis (2022).

Foreign vehicles produce more international transport than Swedish vehicles

Figure 20 shows the amount of tonne kilometres produced by Swedish and foreign vehicles, divided by transport produced within Sweden or across borders (produced by Transport Analysis). The figure shows how many tonne kilometres are produced by several different types of transport: Swedish vehicles that only drive domestically, Swedish vehicles that cross borders (arriving or departing), foreign vehicles that drive within Sweden only (cabotage), and foreign vehicles that cross borders (arriving to Sweden, departing Sweden or just transiting Sweden). All data describe transport produced within Sweden.

Looking at the amount of tonne kilometres, one can see that freight vehicles registered in Sweden dominate the market of domestic transports (see the large red bars compared to the burgundy bars in Figure 20), while foreign registered vehicles dominate the transport to and from Sweden (see the black and grey bars where foreign vehicles are displayed on top). Over time, the foreign trucks continue to take market shares in Swedish international freight traffic. On the domestic market (cabotage), foreign trucks only deliver about 4 percent of the tonne kilometres. There was a dip in the market in 2009, possibly due to the financial crisis, but has remained relatively stable since.

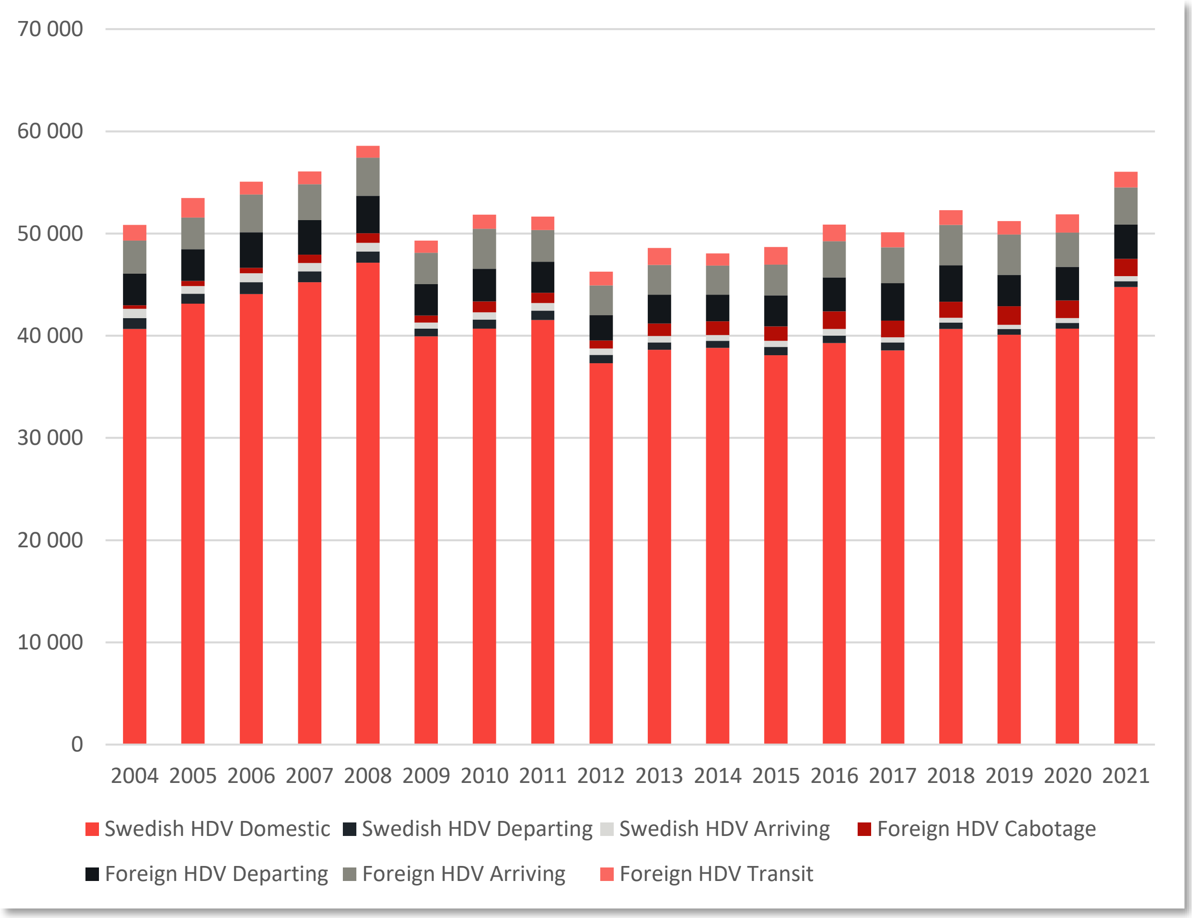


Figure 20: Amount of tonne kilometres, on Swedish roads, by year and based on whether the vehicle is registered Swedish or foreign and whether the traffic is only within Sweden or across borders. Most of the tonne kilometres are produced by Swedish vehicles driving domestically, but foreign vehicles dominate international freight. For 2021, transport by foreign vehicles was extrapolated. Source: (Trafikanalys, 2022)

Thus, foreign trucks dominate freight transport in international transports, to and from Sweden. From Sweden, about 75 percent of the goods were transported by foreign-registered trucks. An even higher proportion is seen for goods transported to Sweden: about 85 percent. However, cabotage (domestic transport in Sweden by foreign-registered trucks) constitutes a relatively small share of the amount of goods transported and the number of domestic transports in Sweden.

What kind of goods would use ERS?

Figure 21 shows road transport by Swedish vehicles by commodity group (the horizontal axis), in terms of the amount of transported tonne kilometres (the red symbol and the right-hand axis), including the share for each distance interval (the bars and the left-hand axis). For example, commodity 2 (coal, lignite, crude petroleum and natural gas) exhibits few tonne kilometres by Swedish vehicles, while commodity 4 (food products, beverages and tobacco) exhibits many tonne kilometres. Further, for food products and beverages, roughly half of the tonne kilometres are on trips of more than 300 kilometres and more than 90 percent trips that exceed 150 kilometres. This indicate that this commodity group have the potential to utilize ERS since it travels relatively long distances. Food and beverages constitute 5 percent of all transported goods in Sweden, and the sector is vastly dominated by road.

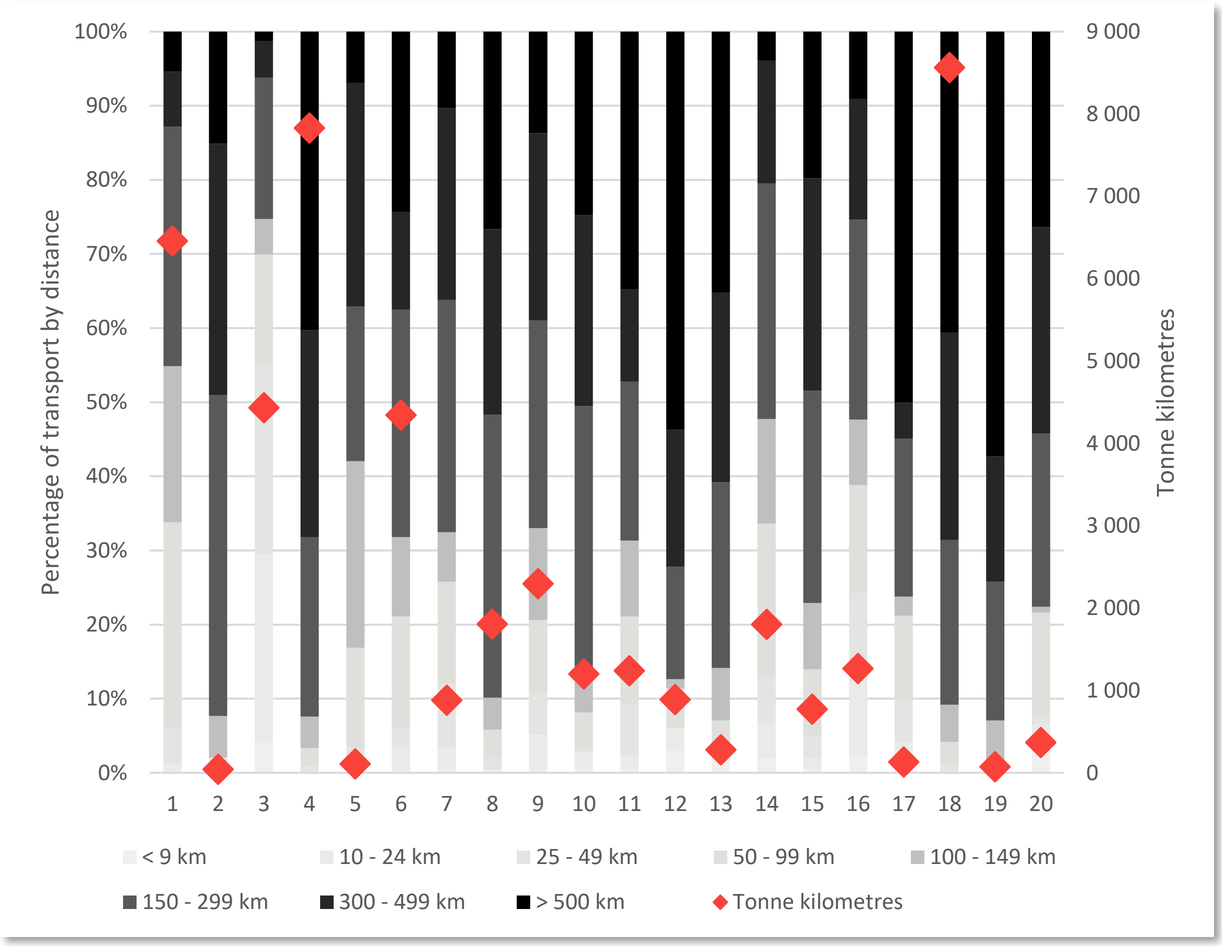


Figure 21: Freight transport by Swedish vehicles on Swedish roads. Bars represent the percentage of each distance interval by commodity group (left vertical axis). Red symbols indicate tonne kilometre (right vertical axis). For example, commodity group 1 consists of about 6 500 tonne kilometres and about 12 % of that involves trips that are more than 300 kilometres. Source: (Trafikanalys, 2022)

Another interesting commodity group is number 18 (grouped goods, or a mixture of goods that are transported together). Roughly two thirds of this group make trips of more than 300 kilometres, which makes it a potential user of ERS. Unfortunately, similar data combinations are not available for foreign vehicles on Swedish roads. Still, data from Transport Analysis indicate that foreign vehicles transport large amounts of grouped goods (commodity 2) in terms of tonne kilometres, as well as wood products (commodity 6) and food products (commodity 4).

These data indicate the type of commodity group that is most likely to be transported in vehicles that use ERS. In short, commodity groups that are dominated by road transport (rather than rail or sea) and that are typically transported over long distances, are the most likely to utilise ERS. Commodity groups that rarely use road transport (based on number of tonne kilometres) but travel long distances when they do use them would, of course, also utilise ERS, but they are unlikely to reap the benefits to the same extent as the commodities that constitutes more tonne kilometres.

What determines the choice of transport mode?

As shown the modal share of road transport is relatively stable in recent years and constitutes a substantial part of the domestic freight transport. However, there are political ambitions to shift from road freight toward rail and sea transport (Regeringskansliet, 2018). Thus, it is worth examining competition between the modes of transport to foresee potential future effects of altered relative prices.

Some researchers suggest a “structural inelasticity” in freight transport (Rich, Kveiborg, & Hansen, 2011; ITF, 2022), in particular for transport routes that exceed 500 kilometres. As noted, only a fraction of the total freight (about 8 %) is transported longer than 300 kilometres. The competition between transport modes also varies with commodity type and geography, i.e. the origin and destination as well as the landscape topography. A Swedish review suggests that rail transport is considered a competitive alternative for only about four percent of the road transport (Transportstyrelsen, 2017). In other words, transport modes function more as complementary services in a multi- or intermodal chain of logistic solutions, rather than being competitive. The reach, speed, flexibility and reliability that road transport offers are generally superior, so price changes do not fundamentally alter mode choice.

An international literature review by the International Transport Forum (ITF) suggests that the competition between road, rail, sea and air transport varies with the type of commodity, length of transport and geography. The mode choice depends on factors such as freight transport costs, freight transit times, reliability and service frequency, and the infrastructure and superstructure (ITF, 2022). For shorter distances, road transport is less expensive than the alternatives. Rail and sea transport do not have the dense networks that benefit road transport, but rail and sea transport do benefit from economies of scale since it is cheaper per transported tonne-kilometre (Transportstyrelsen, 2017; ITF, 2022).

But the actual transport cost is only one factor for a transport buyer. Transport is part of a logistics solution that may include several modes, as well as dependency of the nodes in the system and storage space (Vierth & Björk, 2021). Some commodities are high-value, fragile or time sensitive, which means the transport buyer is more concerned with product security and product safety. Time-sensitive goods such as food require swift delivery and (often) a refrigerated environment during the entire transport period. Since time in storage is also a costly factor for the transporter, road offers the possibility of more flexibility and greater chance of delivering “just-in-time.”

A recent analysis of elasticities found rather different cross-price estimates, between 0,03 and 1,7 for road price and demand for rail (Jourquin, B.; Beuthe, M., 2019). The reason for the large interval lies in the estimation method where aggregated data typically leads to smaller estimates, compared to disaggregated data (ITF, 2022). For different commodities, there are indications of higher cross-price elasticities (price of road and demand for rail transport) for solid fuels and fertilizers and low cross-price elasticities for agriculture products, food and fodder and machinery.

Conclusions

In summary Swedish freight is transported along relatively few but heavily used routes and corridors. Road transport represents 40 percent of all freight tonnage but uses only about 3 percent of the nationwide road network. Further, the modal share for road transport has been relatively stable over the past decades (or has increased, if one looks further back in time). Road transport is predominantly made using vehicles registered in Sweden, but foreign vehicles dominate the international transport within the country (note that ‘international’ refers to all transport coming from, or leaving for, another country, but only covers transport within Sweden). Thus, a key issue for further analysis is how the incentive structure may differ for foreign haulers (compared to Swedish ones), if an ERS is built.

In terms of commodities, data show that the main export product from Sweden is iron ore and other mining products (and to a lesser extent wood products). These products are largely transported by rail and then shipped from the north of Sweden. Overall, it is worth noting that the freight *from Germany* to Sweden has a higher value per tonne, than the freight *from Sweden* to Germany, indicating that Swedes import relatively higher valued goods from Germany. A related conclusion is that *road* freight to and from Sweden is valued significantly higher than freight transported by other modes.

The finding that road transports higher valued goods is supported by the literature which elaborates on the competition between the transport modes. In many cases, there is very low or no competition at all, particularly for shorter transport. Long-haul transport, however, is characterised by more competition between road, rail and shipping, but road still has an advantage for certain types of commodities demand frequent service, high security and/or just-in-time delivery. These include e.g., dangerous goods, luxury goods, food products and transports with mixed goods.

Luxury goods and food products seem to be rather important for domestic Swedish road transport in terms of tonnage. They are also likely to use the ERS since a large proportion of these goods travel long distances. Electrification of road transport will reduce the motive for a modal shift from road to rail, which has been a political objective in Sweden in recent years, based on environmental concerns. Electrification may also increase the relative competitiveness of road transport.

The industry trend toward heavier and longer vehicles for the transport of heavy goods will also make road relatively more competitive. Note, however, that this does not imply that loads will be heavier because statistics show that the average load per vehicle is below the maximum allowed. This suggests that future buyers of transport services will continue to be challenged to find clever logistics solutions, if they wish to utilise the potential of the ERS. More knowledge of these types of logistic alternatives may provide a deeper understanding of the interactions between modes of transport. In some cases, road, rail and sea are in fact complementary services, rather than substitutes.

A possible large-scale roll-out of the ERS is going to be along the TEN-T corridors. The Scan-Med corridor is particularly important for Sweden. The Swedish Transport Administration has sketched a plan for a stepwise roll-out along the busiest roads, but the uncertainty is still large. If the ERS will be built, it seems natural to continue the roll-out along the Scan-Med corridor south through Germany. German actors have indicated the route between Hamburg and Lübeck to connect with a Scandinavian network (Hacker, Jöhrens, & Plötz, 2020). With that position in Germany, Denmark seems almost forced to choose the Copenhagen to Rødby route and connect with Germany across Fehmarn Belt.

WP 3.2 Economic impacts

Introduction

The purpose of 3.2 is to develop a deeper understanding of the results of a previous socio-economic impact analysis of the ERS (Trafikverket, 2021). We conduct a sensitivity analysis of these results and compare them to other analyses.

First, we describe the methods, assumptions, and results from other analyses. We include the following: the Swedish Transport Administration's analysis from 2021 (Trafikverket, 2021); an analysis from 2021 using Swedish data (Börjesson, Johansson, & Kågesson, 2021); and an analysis from Flanders (Belgium) (Aronietis & Vanelslander, 2021). Rather than a comprehensive review of the literature, our aim is to select studies relevant to the Swedish context. We also provide a brief overview of relevant German studies and other studies from the academic literature. Although German studies do not consider the socioeconomic impacts in the same manner as (Trafikverket, 2021), Germany is nonetheless interesting for two reasons: the country is at the forefront of ERS and part of CollERS.

The final part of this chapter summarizes the different assumptions made and presents a sensitivity analysis. We use the calculation tool "Elvägskalk" (same tool used in (Trafikverket, 2021)) to conduct the sensitivity analysis. Our conclusions are presented in the final chapter.

The Swedish Transport Administration's study from 2021

Based on government assignment, the Swedish Transport Administration analysed the socio-economic impacts of ERS (Trafikverket, 2021). The analysis compared the costs of diesel-powered trucks and battery-electric trucks with the costs of trucks powered mainly by electricity via dynamic charging (ERS).

The transition from diesel-powered heavy trucks to electric operation offers two social benefits – reduced operating costs and reduced carbon emissions – which can be compared to the investment and maintenance costs of the ERS. The investment is profitably from a socio-economic perspective if the net benefit cost ratio (NBCR) over the full appraisal period is positive. The analysis assumes an appraisal period of 40 years (2025-2065) and a discount rate of 3.5 percent (Trafikverket, 2021).

The analysis builds four scenarios that reflect possible future development based on assumptions about four key variables (diesel price, emission factor, investment cost and traffic volume). The admixture of biofuels significantly impacts both diesel price and the emission factor. Therefore, the Swedish Transport Administration (2021) has used two different price forecasts for the analysis. Price forecast A represents the current share of biofuel mix (21%), resulting in a relatively low diesel price and, consequently, a high emission factor. The opposite applies to price forecast B, where a higher share of biofuel mix is assumed to meet climate goals (66%), and results in a higher diesel price and low emission factor. The two price forecasts are combined with high/low investment cost and high/low traffic volume resulting in the following four scenarios:

Scenario 1: low admixture of biofuels (low diesel price and high emission factor), low investment cost, high traffic volume

Scenario 2: low admixture of biofuels (low diesel price and high emission factor), high investment cost, low traffic volume

Scenario 3: high admixture of biofuels (high diesel price and low emission factor), low investment cost, high traffic volume

Scenario 4: high admixture of biofuels (high diesel price and low emission factor), high investment cost, low traffic volume

The input data used for the analysis is based on the ASEK 7 Guidelines (Trafikverket, 2020), which represent recommended principles for conducting a cost-benefit analysis (CBA) in the Swedish transport sector. Vehicle costs are assumed to decrease over time, based on the assumption that electrical components and batteries will become cheaper. User charges are also assumed to decrease over time as the number of vehicles using the electric road is increases. A conversion of the energy price according to the energy consumption data results in energy cost per vehicle kilometre for both diesel and electricity-powered trucks. Moreover, it is assumed that biofuel has the same effect on carbon emissions as the electrified alternative. Input variables are summarized in Table 11.

Table 11. Input variables for the socio-economic analysis by the Swedish Transport Administration.

Input Variable	**Unit**	**2025**	**2030**	**2035**	**2040**	**2065**
Additional ERS cost purchase price	MSEK	0.35	0.35	0.24	0.13	0.13
	Percent	50	50	30	10	10
Diesel consumption	l/km	0.25	0.25	0.23	0.21	0.13
Electricity consumption	kWh/km	1.13	1.13	1.03	0.94	0.61
Diesel price – price forecast A Including taxes, excluding VAT	SEK/l	12.16	13.12	14.45	15.79	20.88
Diesel price – price forecast B Including taxes, excluding VAT	SEK/l	12.16	15.03	17.10	19.17	26.56
Electricity price Including taxes, excluding VAT	SEK/kWh	1.08	1.19	1.33	1.4	1.61
Energy cost (diesel) – price forecast A	SEK/vehicle km	2.99	3.23	3.25	3.24	4.28
Energy cost (diesel) – price forecast B	SEK/vehicle km	2.99	3.70	3.84	3.93	5.45
Energy cost (electricity)	SEK/vehicle km	1.58	1.71	1.54	1.47	1.67
User charge High investment, high traffic	SEK/vehicle km		2.01	1.50	1.28	1.20
User charge High investment, low traffic	SEK/vehicle km		4.02	3.00	2.56	2.40
User charge Low investment, high traffic	SEK/vehicle km		2.42	1.80	1.54	1.45
User charge Low investment, low traffic	SEK/vehicle km		4.83	3.61	3.08	2.89
Carbon emissions – price forecast A	CO_2kg/l	1.96	1.96	1.96	1.96	1.96
Carbon emissions – price forecast B	CO_2kg/l	1.54	1.28	1.07	0.76	0.00

Having lower user charges when the investment cost is low might seem illogical for countries using fees to finance infrastructure (as most countries in continental Europe do). The logic in (Trafikverket, 2021) is that lower investment costs imply higher maintenance costs (and vice versa).

Transferring effects to the vehicle differ among the various ERS technologies, where the technique for an inductive rail system requires a higher investment cost than conductive alternatives. Therefore, two levels apply in the analysis or 2030: a low level (approximately SEK 13 million per kilometre) and a high level (SEK 27 million per kilometre). Operating and maintenance costs are assumed to be either 2 percent of the high investment cost or 5 percent of the low investment costs. The reason for the assumption that an inductive rail system is estimated to have lower operating costs is due to its submerged nature, reducing wear on the system and removing friction and exposure from vehicles and debris.

The analysis assumes electric-powered trucks for the ERS system and battery powered trucks in the non-electrified road section (usage on the latter will depend on battery life) (Trafikverket, 2021). 25 percent of the annual average daily traffic is estimated to use the ERS in 2040. Traffic data used for the analysis (high-traffic scenarios) are summarized in Table 12. Low traffic scenarios correspond to half the related values.

Table 12. Traffic data used for the analysis, high traffic scenarios.

Electric road combined with stationary charging	**2030**	**2033**	**2035**	**2037**	**2040**
Electric road total length (km)	2 000	2 000	3 000	3 000	3 000
Number of electric trucks as annual average daily traffic (AADT)	345	676	895	973	1 088
Millions vehicle km other road type	85	309	652	708	792
Millions vehicle km total	339	977	1 629	1 769	1 979
Number of Swedish electric trucks	2 261	6 457	9 255	9 551	9 895
Number of foreign electric trucks	1 130	4 197	6 941	8 118	9 895
Total number of electric trucks	3 391	10 654	16 196	17 699	19 790

Results from the socio-economic analysis for all four scenarios are shown in Table 13. The Swedish Transport Administration (2021) found that investment in ERS in Sweden is only socio-economically profitable in scenario 1, where the admixture of biofuels is kept low combined with low investment cost and high traffic (implying low user charge). Scenario 1 is based on the price forecast A. In contrast, price forecast B includes far-reaching climate investments with a higher admixture of biofuels which, from a societal point of view, leads to a weaker incentive to switch from fossil fuel to electric operation. On the other hand, the incentives for transport operators to switch to electricity are greater with a higher diesel price.

According to the calculations, a high admixture of biofuels decreases emissions more than the operating costs increase. This means that it is socioeconomically profitable to increase the admixture to 100 percent. Therefore, the assumption made about future biofuel admixture is crucial to the assessment of social profitability in the analysis.

Another key assumption built into the Swedish Transport Administration’s analysis is the share of diesel-powered trucks that are converted to electric operation (Trafikverket, 2021). The analysis assumes that a constant and unchanging conversion rate regardless of the share of biofuel admixture and size of the user charge. The reality, however, is that the conversion rate depends largely on both parameters.

Since one of the main effects of electric roads is reduced CO2 emissions, the valuation of these impacts greatly affects the socio-economic profitability. A high valuation increases profitability of the ERS investment while a low valuation has a negative effect on profitability. The Swedish Transport Administration (2021) relies on ASEK´s recommended valuation of 7 SEK/kg (which by international standards is a high valuation). However, it is worth noting that the scenarios that assume a high admixture of biofuels naturally lead to reduced CO2 emissions anyway, which means the socioeconomic profits will be relatively low in such scenarios (see the chapter below The Swedish biofuel (admixture) strategy).

The Swedish Transport Administration (2021) emphasizes several components of uncertainties in the socio-economic analysis, in particular the fact that ERS technologies are at a very early development stage.

Table 13. Main results from the socio-economic analysis by the Swedish Transport Administration (2021).

Transport operator	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
Fuel price	65 560	32 780	89 960	44 980
User charge	-31 210	-25 930	-31 210	-25 930
Charging infrastructure	-2 010	-1 000	-2 010	-1 000
Other vehicle costs	-24 810	-12 400	-24 810	-12 400
Budgetary effects				
Fuel tax	-41 070	-20 540	-41 070	-20 540
User charge	31 210	25 930	31 210	25 930
External effects				
Carbon emissions	89 350	44 670	27 100	13 560
Other emissions	125	60	125	60
ERS cost				
Investment cost	-31 000	-64 500	-31 000	-64 500
Maintenance cost	-31 400	-26 100	-31 400	-26 100
Net present value	21 645	-47 030	-13 105	-65 940
Net present value ratio	0.39	-0.52	-0.21	-0.73
Net socio-economic cost per reduced kg of carbon emissions	5.10	14.40	10.40	41.10

Swedish study by Börjesson et al. from 2021

Börjesson et al. (2021) evaluate the social benefits of developing electric roads for the Swedish highway network and conduct a CBA. The analysis makes several assumptions: Transport carrier behaviour is modeled by the Swedish national freight model system, SAMGODS; overhead power lines (the most mature technology at present) is used; and no electric roads are available outside of Sweden which, according to the authors, likely would increase the benefit of the Swedish ERS due to economics of scope and scale.

Since the benefit of electric roads largely depends on the size of the network, the authors assume three different network scenarios in the model:

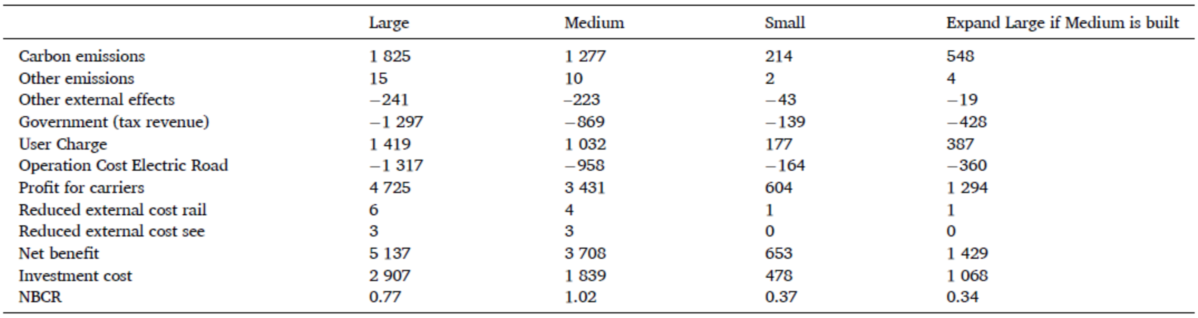
- A small network: E4 between Stockholm and Norrköping (315 km)
- A medium-sized network: E4 between Stockholm and Malmö (1211 km)
- A large network: European roads between Stockholm and Malmö (E4), Malmö and Gothenburg (E6), and the national road Rv 40 between Gothenburg and Jönköping (1914 km.)

Börjesson et al. (2021) analyse the difference between welfare-optimal and profit-maximizing user charges and find that the revenue does not cover the investment cost when the user charge optimizes welfare. If the electric road network is large enough and the user charge is set to optimize profit, then revenue covers investment.

The analysis is based on the forecast year 2030. The appraisal period is 15 years (relatively short due to difficulties in predicting the technical development of batteries and fuel cells after 2040). 25 percent bio-mixing is assumed to meet the EU targets, affecting the external cost of carbon emissions for diesel trucks. A more detailed description of input parameters is given in the chapter below on sensitivity analysis.

As seen in Table 14 the net benefit cost ratio (NBCR) is positive for all three scenarios (involving different assumptions about network size), which suggests that social benefits exceed social costs. A key finding is the significant reduction of carbon emissions from heavy traffic, which represents the second largest benefit. Operation cost savings for carriers appear to provide the largest benefit since trucks fueled by electricity are cheaper to operate than diesel. The authors discuss whether the results can be transferred to other countries, given that Sweden has, on the one hand, low electricity prices but on the other hand, long travel distances relative to population size. The authors also highlight the benefit of coordinating the expansion of ERS roads in Europe due to large economies of scope.

Table 14. Main results for the all network sizes from the socio-economic analysis by Börjesson et al. (2021).



	Large	Medium	Small	Expand Large if Medium is built
Carbon emissions	1 825	1 277	214	548
Other emissions	15	10	2	4
Other external effects	−241	−223	−43	−19
Government (tax revenue)	−1 297	−869	−139	−428
User Charge	1 419	1 032	177	387
Operation Cost Electric Road	−1 317	−958	−164	−360
Profit for carriers	4 725	3 431	604	1 294
Reduced external cost rail	6	4	1	1
Reduced external cost see	3	3	0	0
Net benefit	5 137	3 708	653	1 429
Investment cost	2 907	1 839	478	1 068
NBCR	0.77	1.02	0.37	0.34

Belgian study in Flanders from 2021

As part of the Logibat project, Aronietis and Vanelslander (2021) investigated the economic impact of developing a catenary ERS network for road freight transport in Flanders, Belgium. The model includes two scenarios to investigate vehicles with a single technology adoption as well as hybrid vehicles. The scenarios assume that both vehicle types can use diesel, LNG, hydrogen, electricity from batteries, and electricity from overhead catenary. Rather than using forecasts, the authors use a set of scenarios to examine the impacts of alternative technology adoption in Flanders.

In addition to the scenarios, the model also relies on traffic data and geography as well as technology and operation assumptions. The analysis also includes a segment-level calculation for the entire Flemish road network, which provides emission impacts, user costs, and ERS operator costs and revenues. The appraisal period is 20 years. The reporting of numbers and input data is somewhat ambiguous, which makes a review of the study challenging.

The economics for the network operator differ from the Swedish model approach since the operator must earn back the investment. The authors offer some arguments against government investment including e.g., that public funds may be better used elsewhere, that government should not arbitrarily select businesses to support, and that economic support for road freight transport will threaten the shares of other modes of transport like rail and inland shipping.

However, the study ultimately suggests that it is possible to cost-effectively decarbonize road freight transport with catenary ERS and, further, that the investment required is relatively modest. Extensive network coverage of more than 1 500km in Flanders could be obtained with an investment of less than €2 billion corresponding to less than 0.8 percent of Flanders GDP. Concerning investment level and emissions cost, €1 invested in ERS infrastructure will return emission savings for society of €8.3 over 20 years. The authors conclude by suggesting that the use of public money to accelerate development of an ERS network may be worthwhile.

German reports

WSP’s initial workplan included a proposal to analyse and compare the socio-economic studies conducted in Sweden (see reports above) with similar international reports. The workplan suggested a focus on German reports, given their collaboration in CollERS and the fact that the country is considered to be at the forefront of ERS development. Further, the workplan called for an assessment of key factors that may lead to differing conclusions with respect to socio-economic impacts, including e.g:

- Varying total traffic patterns with respect to ERS routes
- Varying assumptions about the percentage of trucks that would be converted for use on an ERS. This dependent variable can lead to large differences in conclusions, regardless of whether it is an endogenous or exogenous variable in a given model.
- Different assessments with respect to Total Cost of Ownership for ERS
- Differences in Total Cost of Ownership for other non-ERS alternatives (e.g., costs and emissions from other fuel solutions, how the biofuel mixture affects both costs and emissions, etc).
- Differences in the size of subsidies, taxes, or difference in approach for including/excluding user fees, etc.
- The size of the system which is connected to so-called Mohring effects/network effects (i.e., a large network allows haulers to have a large park, single relationships only allow trucks to have customized vehicles for that range relationship. As such, it becomes more of a niche market)
- Differences in assumed investment costs per km
- Differences in depreciation period

Based on our desktop searches for relevant reports on the field, we have not been able to identify any German reports that address socio-economic calculations for ERS. We have, however, identified a limited number of related reports that cover Total Cost of Ownership of ERS and non-ERS options. Further, we have been in contact with our German colleagues within CollERS and asked if they had knowledge of such studies, but they were not aware of such reports.

Other relevant literature

The academic literature (articles in scientific journals) covering investments in full ERS networks is fairly thin (see e.g., (Jang, 2018) for an overview). Most articles tend to analyse a single stretch of road or highway, while assuming a few given origins/destinations (Börjesson, Johansson, & Kågesson, 2021). Some articles took a strategic view such as:

- Large-scale implementation of electric road systems: Associated costs and the impact on CO2 emissions (Taljegard, Thorson, Odenberger, & Johnsson, 2020)
- Potential for reducing greenhouse gas emissions by electrifying freight transport on the Swedish E-road network (Jussila Hammes, 2020)

Total cost of ownership (TCO) is often studied. The purpose TCO studies is to determine the viability of different technologies from a user perspective. The latest report is (ITF, 2022).

Sensitivity analysis

As noted in the summaries above, studies tend to differ in terms of results and focus areas. Some studies analyse socio-economic profitability, while others analyse more business-oriented measures. Both the Swedish Transport Administration and Börjesson et al. analyse modal share (the share of road freight using ERS). Table 15 summarizes the conclusions of these two Swedish studies as well as the Belgian study. Note that the modal share is a *result* from the studies, regardless of whether it is endogenous or exogenous in the respective models. Note that modal share in the Swedish studies refers to the share of all heavy truck kilometres in Sweden (not the share on the ERS roads).

Table 15. A summary of major conclusions from previous studies examining socioeconomic impacts of ERS.

	The Swedish Transport Administration, 2021	Börjesson et al., 2021	Belgian study in Flanders, 2021
Economic profitability	Net benefit cost ratio: Scenario 1: 0.39 Scenario 2: -0.52 Scenario 3: -0.21 Scenario 4: -0.73	Net benefit cost ratio for large network: 0.77	CO2 reduction per € 1 invested: €8.3
ERS modal share	25%	31%	-

A key assumption is the total amount of freight traffic expected on future ERS roads. If the amount is high, the total time gain and the effect on pollution are potentially high. More traffic also means that the repayment period (for countries using fees to finance infrastructure investments) is reduced. The total amount of traffic is much higher in Belgium, which might be one of the main explanations for more positive results.

Another central assumption is the Total Cost of Ownership for ERS and for competing transport methods such as BET and diesel. This includes both vehicle cost (investment and maintenance) and fuel/energy cost (which depends on price and consumption).

Investment and maintenance cost for building ERS is also an important factor for socio-economic profitability.

System size might also be an important factor. It is reasonable to assume that an ERS has significant economies of scope. If ERS is built only for a select number of routes/roads, trucking companies will only buy ERS trucks that mainly travel on these routes. If there is a network of ERS, trucking companies can invest in larger fleets of ERS trucks that can cover a larger area. Börjesson et al. (2021) find that there are economies of scope in ERS, but only up to a certain size. Classic reasoning about economies of scope assumes that investments are duplicable, which is clearly not the case for ERS (there are profitable and less profitable investments). Although there may be no limit to the economies of scope-effect, there is likely a limit to how many profitable investments can be made. The Swedish Transport Administration (2021) assumes that trucks driving more than 40 percent of their total mileage on ERS roads will be equipped for dynamic charging. This is an exogenous assumption (i.e., the ERS share is not affected in Elvägskalk by changing the ERS investment). Whether or not 40 percent is the correct number is debatable, but it is certainly reasonable that the effect itself exists, i.e., increases in ERS network size likely increases the share of trucks using ERS on other networks.

Table 16 identifies key assumptions when comparing the various studies. Due to the lack of input data from the Belgian and German reports, our sensitivity analysis focuses primarily on the two Swedish studies (Swedish Transport Administration (2021) and Börjesson et al (2021). Although Börjesson et al. developed three scenarios (corresponding to different system sizes), comparisons in the table are made based on the large system size (1 914km), as it is approximately the same size as the network analysed by the Swedish Transport Administration.

Table 16. Assumptions in the ERS analyses.

	The Swedish Transport Administration, 2021	Börjesson et al., 2021	Belgian study in Flanders, 2021
System size	2 000 km	1 914 km	1 500 km
Investment cost per km	Low cost: € 1.3 million High cost: € 2.7 million	€ 2.5 million	€ 1.27 million
Operating and maintenance cost per km and year	With low investment: €0.07 million With high investment: €0,05 million	0	€0.11 million
Carbon emission valuation	0.65 €/kg	0.114 €/kg	0.106 €/kg
Appraisal period	40	15	20
Additional ERS cost, purchase price (2030)	€35 368	€69 000	-
Diesel price per litre (2030)	€1.31 (price forecast A) €1.5 (price forecast B)	€1.53	-
Electricity price per kWh (2030)	€0.12	€0.079	-

One parameter that differs between the studies is the appraisal period: the Swedish Transport Administration (2021) assumes 40 years (2025-2065) based on ASEK 7 Guidelines; the Belgian study by Aronietis and Vanelslander (2021) assumes half as long; and Börjesson et al. (2021), assume a relatively short appraisal period of 15 years (due to difficulties in predicting the development of batteries and fuel cells after 2040). Even with an appraisal period of 40 years, the authors calculate based on 35 years because it is assumed that the appraisal period starts at the start of construction, instead of start of traffic use (which is the standard assumption). This means that there is no traffic in the first five years. Therefore, we use 40 years in the sensitivity analysis to examine the differences. Scenario 1 shows the greatest effect, which is expected as the scenario assumes a low admixture of biofuels (unlike scenario 3). We also adopt the appraisal period from Börjesson et al. (2021) and, as expected, the socioeconomic profitability decreases when assuming a shorter appraisal period (15 instead of 40 years). Further, we find that the only scenario that showed a positive net present value, becomes negative (i.e., not profitable from a socioeconomic perspective).

The Swedish Transport Administration (2021) analyses two levels of investment costs. The low level (€1.3 million per km) is applied in scenarios 2 and 4 and is consistent with the investment level by the Belgian analysis (Aronietis & Vanelslander, 2021) The high level (€2.7 million per km), which corresponds to the investment in Börjesson et al. (2021), is applied to scenarios 1 and 3. The two investment cost scenarios in the Swedish Transport Administration's analysis are related to two different technologies (the inductive technique requires a higher investment cost than the conductive alternative). If the high level of investment cost is also applied in scenarios 1 and 3, the most interesting result is that scenario 1 – with the low investment cost and previously positive net present value –instead becomes negative.

Operating and maintenance costs are estimated as a percentage of the investment cost, either 2 percent of the higher investment cost per year or 5 percent of the lower investment cost per year. As noted, an inductive rail system requires a higher level of investment but is estimated to have lower operating and maintenance costs due to its submerged nature, reducing wear on the system and removing friction and exposure from vehicles and debris (Trafikverket, 2020). Due to the short appraisal period, Börjesson et al. (2021) disregard the annual operation and maintenance cost. If the operating and maintenance costs are excluded from the Swedish Transport Administration's analysis, while keeping the appraisal period unchanged, the socioeconomic profitability increases significantly: scenario 3 shows a positive net present value. However, the comparison becomes somewhat misleading when we assume an appraisal period of 40 years, because the assumption of disregarding operating and maintenance costs is based on the use of a shorter appraisal period.

In Börjesson's analysis, carbon emissions are valued at 0.114 €/kg, according to the Swedish appraisal guidelines from 2019. The Swedish Transport Administration updated this value significantly in their new guidelines to 0.7 €/kg (1 April 2020), which is applied in the analysis by the Swedish Transport Administration (2021). Not surprisingly, a lower carbon emission value reduces the socioeconomic profitability. Scenario 1 no longer shows a positive net present value when applying the lower valuation from Börjesson et al. (2021). The Belgian study in Flanders, which reports a result of €8,3 emission savings per €1 invested over the following 20 years, uses an even lower valuation than Börjesson et al, at 0.106€/kg. If instead, they had used the Swedish Transport Administration's valuation of 0.7 €/kg, their savings would have been significantly higher – up to €50 per €1 invested.

The additional cost for hybrid trucks equipped with a battery range of 100 km is estimated at €69 000 in Börjesson et al. (2021). A smaller battery with a range of 10-20 km would entail a total additional cost of €50 000. The Swedish Transport Administration (2021) has used an additional cost of the hybrid in relation to a diesel truck of 50 percent, corresponding to a significantly lower price than Börjesson et al assume (€35 368). However, the range of the battery is not specified, which makes it difficult to say whether the trucks are comparable. Thus, results varying depending on which of Börjesson's purchase prices are applied in the sensitivity analysis. The highest price of €69 000 results in negative profitability for all scenarios, while scenario 1 still shows profitability (but significantly lower).

The electricity price in Börjesson's analysis is based on the spot price in 2019 and the Swedish Energy Agency's forecast for 2030, resulting in a price of 0.079 €/kWh. In contrast, the Swedish Transport Administration's analysis relies on ASEK 7 Guidelines, resulting in a price of 0.12 €/kWh in. By adopting the electricity price used in Börjesson et al. (2021), profitability increases, but scenario 1 remains the only one with a positive profitability. The benefit-cost ratio for scenario 3 is around zero and is thus considered undefinable. An interesting aspect of the sensitivity analysis is to examine the outcome when electricity prices rise, as is expected with social development. If prices double to 0.24 €/kWh, no scenario is considered profitable. As such, the assumption about future electricity prices is central to the outcome.

Table 16 shows different diesel prices based on two different price forecasts (in turn based on the share of biofuel). Price forecast A represents the current share of biofuel (21%) resulting in the lower diesel price of 1.31 €/l. Price forecast B represents a higher share of biofuel (66%), the level required to meet the climate goals, resulting in the higher diesel price of 1.5 €/l. Börjesson et al. (2021) assume that the diesel price is 1.53 €/l in 2030. Prices include fuel tax but not VAT. Even if Börjesson et al. (2021) assume a lower biofuel mix than is assumed in price forecast B (25% instead of 67%), they still forecast a higher diesel price in 2030 than the Swedish Transport Administration (2021), which suggests uncertainties with respect to future fuel prices.

The Swedish biofuel (admixture) strategy

By comparing the Swedish Transport Administration's scenarios 1 and 3 (or 2 and 4), one can see that a high admixture of biofuels means that the benefits of ERS decrease by 44 percent. This is logical: If you assume that the goal for CO2 emissions is already reached by high admixtures, other means for reaching the targets will be less profitable. Given the importance of this result, we dig deeper into the details of the Swedish admixture strategy in this chapter

Biofuels are a renewable source of energy used as fuel for combustion engines. The reduction in CO2 emissions caused by mixing biofuels with fossil fuels depends on the share of biofuels that are mixed into fossil fuels. The direct effect on emissions is one of the main arguments in favour of increasing the share of biofuel to reach emission reduction targets (2030 and 2040) set by the Swedish government (Trafikverket, 2020).

In comparison to other measures (e.g., the vehicle fleet becoming more electrified, more fuel-efficient vehicles, reducing traffic by increasing the fuel price, etc), increasing the share of biofuels has the lowest marginal cost in reducing CO2 emissions both between 2021-2030 and the following period 2031-2040. Biofuels are also estimated to contribute the most to reducing emissions during the 2021-2030 period (Trafikverket, 2020).

Biofuel share in Sweden, EU and Globally.

In 2017, the Swedish government enacted a law regulating the share of biofuels to be mixed with fossil fuel in transportation (see Table 17, (Regeringskansliet, 2017)). The law stretches from 2020 to 2030. As a consequence of the Russian invasion of Ukraine and its impact on fuel prices, the Swedish parliament decided to freeze the annual increase in biofuels in 2023 to the level of 2022 (Regeringskansliet, 2022).

Table 17. The share of biofuels mixed into fossil fuels, as required by regulation in Sweden from 2020-2030. Source, Regeringskansliet (2017 & 2022).

Year	Petrol	Diesel
2020	4.2	21
2021	6	26
2022	7.8	30.5
2023	7.8	30.5
2024	12.5	40
2025	15.5	45
2026	19	50
2027	22	54
2028	24	58
2029	26	62
2030	28	66

All EU countries (except Portugal) and the UK had a target to achieve a 6 percent reduction in CO2 emissions from transportation by 2020 through the mixing of biofuels. Sweden’s target was the highest share of biofuels with a mix of 4.2 percent in petrol and 21 percent for diesel (ePURE, 2020). The EU´s renewable energy directive (RED II) requires member states to ensure fuel suppliers provide at least 14 percent of its energy as renewable energy by 2030 (European Union, 2018). Indeed Sweden´s current and planned share of biofuels by 2030 (28 percent share in petrol and 66 percent in diesel) is exceptionally high in comparison to the EU´s current goal by 2030.

The law regulating biofuel mixtures in Sweden was decided by the parliament, but has been criticized by the political opposition, who argue that the increase in biofuels is too high. In September 2022, there was an election in Sweden that resulted in a change of government in favour of the opposition. The new government could alter the planned increase in biofuels, but this is uncertain. However, given the opposition’s previous stance, we believe that it is likely that the future planned share of biofuels will be lower than what is currently projected.

Demand and supply

North America, Europe and several Asian countries are considering implementing policies aimed at accelerating the demand for biofuels. A milestone of Europe´s goal Fit for 55 is to reduce the greenhouse gas emissions from transport fuels by 13 percent in 2030. To achieve this, the European Commission estimates that the share of biofuels needs to be 28 percent by 2030, twice as high as the current target of 14 percent (IEA, 2021).

To achieve the 2030 goals, Sweden is expected to have to increase the total amount of biofuels by 70 percent (Trafikverket, 2020). Sweden is already one of Europe´s highest consumers of biofuels and a majority (85 percent) is imported, mainly from The Netherlands and Finland. Since biofuels are bought on the international market, Sweden is heavily dependent on other countries' production and consumption of biofuels (Energimyndigheten, 2018). Trafikverket (2020) regard the future supply of biofuels as the main concern in being able to fulfil the planned increases in the share of biofuels (see Table 17). All else equal, if Sweden is not able to increase the supply of biofuels as the law requires (Regeringskansliet (2017)), and must instead rely on the available supply today, then traffic from conventional cars will have to be reduced by about one-third to reach the goal of 2030. To achieve such a reduction in traffic, it is estimated that today's fuel prices need to double (from 2 Euro/l to 5 Euro/l). The marginal cost to society would be 2,7 Euro/kg of CO2, which is considerably higher than the expected marginal benefits, which are estimated by the Swedish transport administration's ASEKs 7 guidelines to be 0,7 Euro/kg CO2[14].

The Swedish government committed in July 2022 to investigate the further development of a bio-economy, expressing a need to further increase the production of biofuels in order to phase out fossil fuels within the transport sector. Domestic production of biofuels is considered a strategic national defense matter. The lead investigator of this study is expected to provide suggestions on policies aimed at incentivizing production of biofuels. The investigation results are expected no later than the 15th of February 2023 (Kommittédirektiv 2022:77, 2022)

Cost efficiency of biofuels

Based on a review of the current literature, Trafikverket (2021) concludes that increasing the share of biofuels is the most cost-efficient method for reducing CO2 emissions by 2040. Since pure diesel emits about 2.6 kg CO2 per litre when used in a combustion engine (Drivkraft Sverige, 2019), the cost of reducing CO2 emissions with biodiesel is between 0.12 and 0.23 Euro per kg.

If one considers the full life cycle analysis of biofuel, the cost per CO2 emission reduction increases by about 25 percent, implying a total cost of reducing one kg of CO2 of between 0.44 to 0.29 Euro. Since the cost of reducing CO2 is lower than the Swedish Transport Administration' s marginal benefit (value) of CO2 emission, increasing the share of biofuels is the most economically cost-efficient approach.

To conclude

Increasing the share of biofuels is seen as the most cost-efficient policy in Sweden to achieve the 2030 and 2040 targets for reducing CO2 emissions from the transport sector. However, there are several reasons why Sweden's current policy of increasing the share of biofuels may not be pursued in the near future:

- The new government (September 2022) is critical to the planned increase of biofuels and have pledged to reduce or pause it.

---

[14] The exchange rate of 1 Euro is the equivalent of 10 SEK is assumed.

- Only 15 percent of biofuels are produced domestically, indicating a relatively immature domestic production.
- Relative to the EU and Globally, Sweden has planned a very high increase in the share of biofuels (66 percent). Sweden imports most of its biofuels and plans to increase demand by 70 percent by 2030, at a time when global demand is expected to rise exponentially.
- Policies aimed at increasing the domestic production of biofuels are only being investigated at this stage and unlikely to be implemented in the near future.
- If Sweden is not able to increase biofuel production (imported and domestic) to reach the 2030 target, fuel prices would have to more than double, resulting in a very high marginal economic cost for reducing CO2 emissions (2.7 Euro/kg).
- Trafikverket (2021) assumes that biofuels have zero CO2 emissions per litre, which is not necessarily correct.

Conclusions and discussion

The sensitivity analysis is based on the Swedish Transport Administration’s results. Using the calculation tool “Elvägskalk”, the assumptions of Börjesson are being applied to all of the Swedish Transport Administrations’ scenarios. In addition, a German annual average daily traffic (AADT) has been applied to highlight the importance of the traffic volume for profitability. Table 18 summarizes the findings from the sensitivity analysis.

Table 18. Sensitivity analysis of the Swedish Transport Administration’s results presented as NBCR.

Assumptions varied in the sensitivity analysis	Scenario 1: low admixture, low cost, high traffic	Scenario 2: low admixture, high cost, low traffic	Scenario 3: high admixture, low cost, high traffic	Scenario 4: high admixture, high cost, low traffic
The Swedish Transport Administration’s calculation	0.39	-0.52	-0.21	-0.73
Investment cost €2,5 million	-0.04	-0.52	-0.46	-0.73
Disregarded operating and maintenance costs	1.8	-0.32	0.59	-0.62
CO2 valuation of 0,114 €/kg	-0.8	-0.93	-0.58	-0.85
Appraisal period 15 years	-0.51	-0.86	-0.73	-0.92
Appraisal period 40 years	0.47	-0.49	-0.18	-0.71
Additional ERS cost purchase price of €50 000	0.3	-0.76	-0.9	-0.97
Additional ERS cost purchase price of €69 000	-0.32	-0.77	-0.93	-0.97
Electricity price of 0,24 €/kWh (doubled)	-0.12	-0.7	-0.73	-0.91
Electricity price of 0,079 €/kWh	0.63	-0.44	0.02	-0.65
German AADT	2.82	0.32	1.17	-0.26

As shown in Table 18, CO2 valuation is an important factor for the profitability of ERS. The Swedish Transport Administration (2021) uses the official Swedish recommendations, which means that the calculation is comparable with calculations made for other infrastructure investments made in Sweden. The Swedish CO2 valuation is high from an international perspective. If the Flanders study would have used the Swedish CO2 value, the marginal social benefit of CO2 reduction would have been 51 Euro per invested Euro (0.65/0.106*8.3 = 50.9).

However, if one assumes that CO2 reduction goals are already achieved through other means (e.g., requiring high admixtures), then the profitability of achieving it through these means instead (an ERS) will necessarily be less profitable. As seen by comparing the Swedish Transport Administration's scenario 1 and 3 (or 2 and 4), a high admixture of biofuels means that the benefits of ERS decrease by 44 percent. It is beyond the scope of this report to evaluate Sweden's biofuel strategy, but we emphasize that the strategy is far more ambitious than the rest of the EU's and that it likely decreases the profitability of other means to reach the CO2 targets (regardless of whether the strategy is successful or not).

Another factor that differentiates Sweden from central Europe is the low AADT. Our analysis shows that German ERS investments will most likely be highly profitable, based on their higher AADT (and also assuming the same values for other key assumptions like the admixture strategy as in (Trafikverket, 2021)). Based on AADT data from (Jöhrens, 2020) and (Trafikverket, 2021), the AADT on German ERS roads is 175 percent higher than on the Swedish ERS roads. The benefits in Elvägskalk are proportional to AADT. The 175 percent estimate is based on the highest trafficked stretches, which means that it is most likely an underestimation of the difference between the countries, since German roads have a higher proportion of those stretches.

As with the CO2 valuation assumption discussed above, the appraisal period affects profitability calculations. It seems reasonable to assume 40 years (the official Swedish recommendation), which makes the calculations comparable with those for other infrastructure investments made in Sweden. We noted a small error in (Trafikverket, 2021): the appraisal period is assumed to start when the investment starts instead of when it opens for traffic. Correcting for this makes the benefit cost ratio slightly higher.

The focus of Chapter 3.2 has been on comparing studies of national ERS investments. The current socioeconomic studies are either focusing on national networks or on single corridors going through more than one country. However, it is questionable whether this is the correct perspective. Since the EU has cohesive policies for the transport sector's CO2 emissions, there is an argument that the same should hold for development of ERS. The current perspective on the Swedish ERS strategy is that it is to be seen as an infrastructure investment. This perspective makes it logical to do a national cost-benefit-analysis. If instead ERS is treated as an environmental policy measure, then studies should focus on the EU's investment in ERS, especially if the funding will come from the EU (through CEF). The fact that ERS and, to a larger extent Battery Electric Trucks, are regulated in the EU's Alternative Fuels Infrastructure Regulation (AFIR), would seem to make the case for treating them as an environmental policy measure, and to assessing the socioeconomic consequences accordingly.

WP 4 Effects on the economy of an investment in ERS

In this section, the effects on the regional economies of the manufacturing of ERS elements and the construction of the proposed ERS network are calculated. Effects on the economy refer to the number of additional jobs that are created and the addition to Gross Regional Product (the regional equivalent to GDP). Specifically, it is the jobs directly connected to the actual ERS investment that is the main focus, not larger structural effects that might emerge from changes in the infrastructural system once the ERS network is up and running.

The effect is compared to a basic scenario in which no ERS investment is made, i.e. it is only additional jobs specifically related to the ERS investment that is being calculated. Differences between the four technologies are calculated, as well as differences depending on where the manufacturing might take place.

The study is divided into two parts; first estimates of the required materials per different ERS technology are made. This is then used as input for a regional model that calculates the total effect on job creation, both directly from the manufacturing of ERS elements and the increased demand in the supply chain.

Required data to estimate effects on the economy

In order to estimate the effects on the economy of an investment in ERS, several input data and assumptions are required. The following parameters or assumptions have therefore been identified as necessary for the assessment, see Table 19.

Table 19. Table of required parameters/data for this work package.

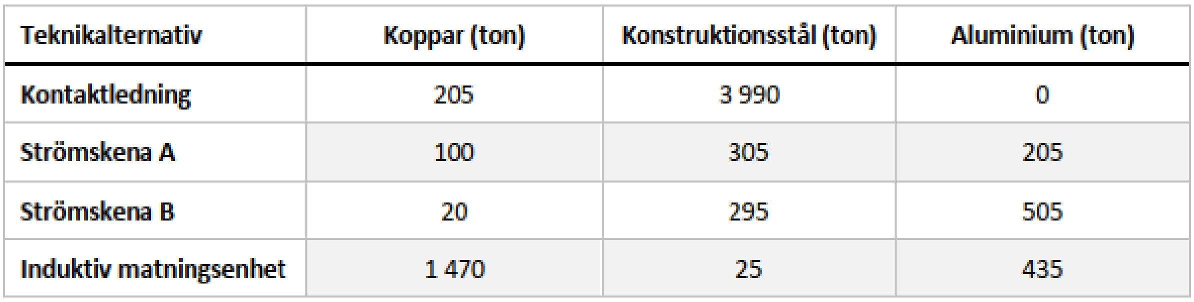
Parameters	**Data/assumption**	**Units**	
Estimate of material used for deloying ERS	Data	ton material / km	
Estimated km or ERS that will be built	Data	km	
Overall approximation of how the required material is ditributed within the production (per sector)	Assumption	Ton material / sector	
Overall approximation of how the production is distributed between national and international production	Assumption	Percent as national production (Sweden)	Percent as international production
Overall approximation of how the production in Sweden is distributed geographically	Assumption	Geographically spread	

Estimation of material used for deploying ERS

The first conclusion in this work package was that there seems to be very limited available data on material used for deploying ERS today, as only a few demonstration tracks have been built around the world. The fact that there are also different ERS-technologies, with different needs of materials, makes the total km of built ERS even smaller once they are separated on each technical solution. On top of that, basically all technologies are in a very early development stage, meaning that system designs are still continuously being evolved and concepts are incrementally reviewed and adapted to fit new arising demands or technical requirements on the different systems. In the end, this has a high impact on the required materials for each technology.

The most progressed work on this topic seems to be the work made by WSP in the road plan for the ERS pilot at E20 in Örebro. In the report *Vägplan E20 Hallsberg – Örebro, Elväg, Brändåsen – Adolfsberg, Miljökonsekvensbeskrivning, 2021-01-22* (eng title: Roadmap, E20 Hallsberg – Örebro, Elväg, Brändåsen – Adolfsberg, Environmental impact statement), there is a subchapter covering required materials for deploying the different ERS-technologies, see Table 20.

Table 20. Table of required parameters/data for this work package.



Teknikalternativ	Koppar (ton)	Konstruktionsstål (ton)	Aluminium (ton)
Kontaktledning	205	3 990	0
Strömskena A	100	305	205
Strömskena B	20	295	505
Induktiv matningsenhet	1 470	25	435

In the WSP CollERS project, there are project members that have previously been involved in the work behind the road plan for E20 Örebro and hence, experiences and knowledge from that assessment have been utilized for this work. A favourable condition in this work package is that WSP is allowed to make contact with the ERS-suppliers to ask for more input, which was limited in the previous work. This mainly concerns the estimates regarding required materials for the inductive technology, where the current estimates are impacted by large uncertainties, especially for the coils. Therefore, WSP has made contact with Electreon and asked for more input on required materials for the coils in the road.

As the data is presented for the specific pilot stretch, constituting 21 km in one direction or 42 km in both directions, this data has to be translated into required materials per km. By doing this, the following results have been obtained, see Table 21.

Table 21. Estimated required materials in ton per km.

	Copper (ton/km)	Construction steel (ton/km)	Aluminum (ton/km)	Rubber/Plastic (ton/km)
Siemens eHighway	5,0	95	0	0
Evias	2,3	7	4,9	3,8
Elonroad	0,5	7	12	2,8
Electreon	35	1	10,4	23,9

The result can also be illustrated in a graph per ERS-technology, see Figure 22 below.

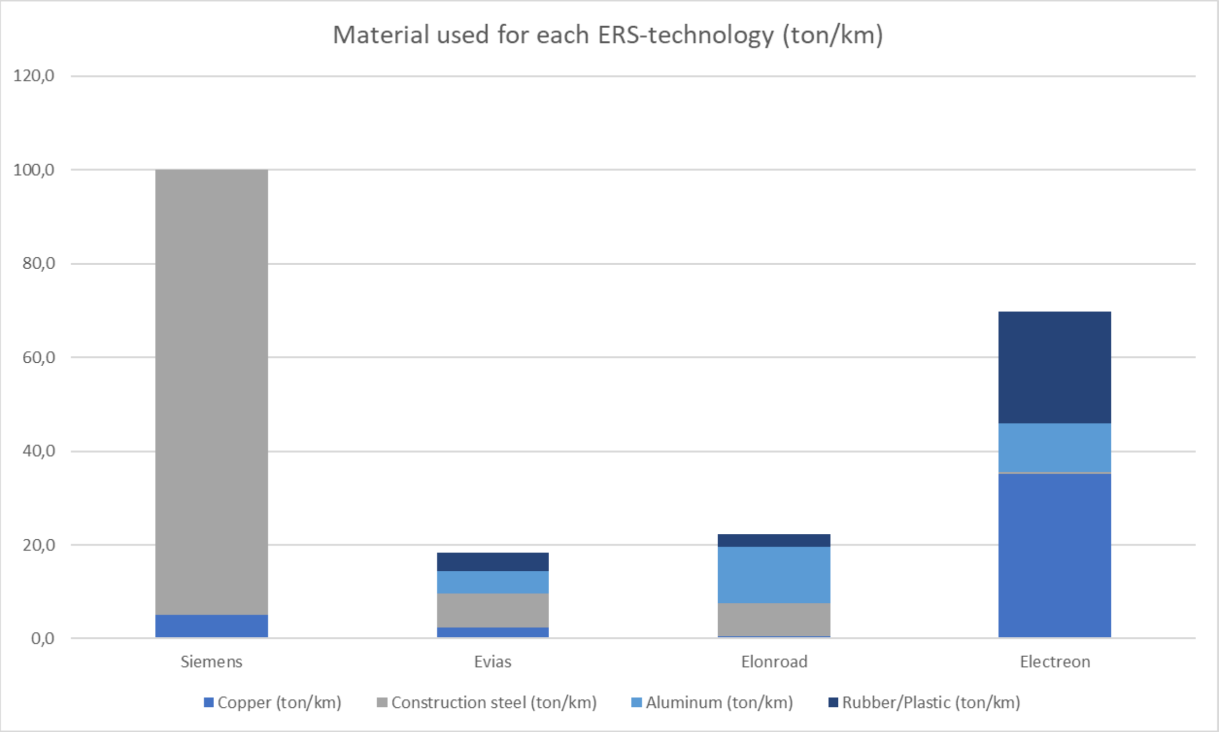


Figure 22. Estimated required materials in ton per km, divided per ERS-technology.

For these numbers, the following assumptions have been made:

1) 100% of the road are equipped with ERS
2) Substations from electricity grid along the ERS to the ERS are NOT included (note: number of substations differs between ERS-technologies and will change depending on requirements on the system that are yet not set)
3) Safety barriers are NOT included
4) Grid along the road is NOT included
5) Possible service routes are NOT included

The reason for these restrictions on the assumptions is mainly that there is yet no basis for the extension of those arrangements. A general assumption is that regardless of which ERS-technology that is built, each built km of ERS will require an additionally 1000 meter of cable / km for the grid along the ERS, which are not included in the numbers above.

In Table 22, the following elements have been included for each ERS-technology:

Table 22. Elements that are included in the estimation of material used.

	Siemens eHighway	**Evias**	**Elonroad**	**Electreon**
Elements that are included	- Output cables - Contact wire - Carrying line - Carrying threads - Service route - Steel, wiring infrastructure	- Distribution cables - Cable cabinets - Control cabinets - Rail	- Distribution cables - Rail	- Distribution cables - Cable cabinets - Control cabinets - Coils

Estimated km or ERS that may be built

In Sweden, there is currently no decision made on if ERS will be deployed, and if so how many kilometre ERS that will be built. The Swedish Transport Administration has, however, presented a proposal for a deployment plan for ERS to the Swedish government, as part of the governmental assignment they got in 2020/2021 (Trafikverket, 2021). In Table 23, the proposed network and its corresponding km of ERS is presented.

Table 23. Proposal for a deployment plan for ERS made by the Swedish Transport Administration in 2021.

Deployment steps	**Suggested km of ERS**
Step 1 **(Malmö – Stockholm, incl. connections)**	Approx. 750 km
Step 2 **(Malmö – Göteborg, incl connections)**	Approx. 350 km
Step 3 **(Göteborg – Stockholm, incl. connections)**	Approx. 600 km
Step 4 **(Complementing routes)**	Approx 700 km
Complete network	Approx 2 400 km

The calculations in the later section are based on the proposed full network of approximately 2 400 kilometre of ERS. Details regarding the calculations are presented in the later section *Calculation of effects on the economy*, among other details and assumptions for the calculation.

Overall approximation of how the production is distributed between national and international production

Based on the national input-output tables (which are statistical descriptions of the flow of products between different sectors of the economy) it is possible to approximate how much of the materials are being produced domestically and how much is being imported. In statistical terms, NACE industry 27, production of electrical equipment, is being applicable here. Of all input products in this industry, 42 per cent are imported. Of the specific required materials for ERS, copper, construction steel and aluminium are considered basic metals, of which 48 per cent are imported. Rubber/plastic has an import ratio of 64 per cent.

Overall approximation of how the production in Sweden is distributed geographically

Since no decision is yet made on what ERS technology will be employed, there are no plans on where the elements will be produced. Therefore there is still considerable uncertainty on what regional effects on the economy that can be expected.

To handle this uncertainty in the calculations, an approach of alternative scenarios, or cases, will be applied. The different regions are selected, to represent three different structures of industry, and will serve as examples of what kind of effects can be expected, both in volume and in structure. There is nothing that says that these regions are more likely than any other to host the manufacturing of ERS elements. Rather, they should be viewed as templates. If the manufacturing will take place in a region of similar size and economic structure, similar effects can be expected.

The following regions have been selected to serve as typical cases; Stockholm county, Västra Götaland county and Västerbotten county. Stockholm county is the largest region in Sweden, with an industrial structure heavily dominated by services. It is an urban region where productivity and levels of education are generally high. Västra Götaland county is dominated by the manufacturing industry. Input products and subcontractors are easily available within the region. Västerbotten county, finally, will represent the more rural regions in northern Sweden. They are generally smaller and to a large degree dominated by the production of raw materials, such as mining and forestry. But they are currently also in the center of a new wave of industrialization, such as car battery production and new steel production technologies.

Results of the calculations will be presented for each of the three regions as alternative scenarios, without saying anything about the likelihood of where the production will take place.

Calculation of effects on the economy

Theoretical framework

The reason for calculating the effects on a regional rather than on a national level is based on the underlying theoretical framework. This is often a helpful way of understanding events in the world around us. A theoretical model that is applicable in this case is the New Economic Geography.

The question of what drives and explains regional development and how it can be affected is not new but has been discussed for a long time. It is based on economical location theories that were formulated more than a hundred years ago. Basically, these theories predicted that the choice of location for the manufacturing industry was decided by the access to raw materials and other production by access to the market.

The New Economic Geography is based in globalization. The theory focuses on understanding and explaining the development in the western world during the transition from manufacturing to services. Access to a qualified labour force is more and more what drives regional development. As the economy gets even more specialized the need for specialized labour also increases. The new economic geography means that size and density are two important competitive advantages. Large and dense regions have fundamentally better conditions for development than small and scattered regions. There are several reasons for this, but the main reason is that it is easier for companies to find qualified labour in large and dense environments. Correspondingly, it is easier for individuals to find jobs that fit their competence profile, particularly if the household consists of partners with different qualifications.

A multitude of studies supports the assumption that the development of cities and regions can be explained by size and density. It is important to point out that these relationships not only are valid for the major urban regions of Sweden but can also be observed in smaller regions and on different scales. Generally, larger regions tend to grow more than smaller regions in their functional context, no matter the geography. In regions where cities shrink, larger cities tend to shrink less than surrounding cities.

The advantages of size and density have placed the focus on the importance of functional regions, which have accelerated a process in planning of expanding the labour market regions. This process is partially about getting closer to the surrounding world, but also about increasing the everyday geography of people. By improving transport infrastructure that facilitates commuting, the world has become smaller. This is also known as regional growth. Functional regions are becoming more important for the development of society at large.

The New Economic Geography is now being considered a sound theoretical basis for explaining the development of cities and regions. Even if many of its foundations are still valid, there might be reasons for finetuning the theory as society changes. It is being challenged by new perspectives on sustainable regional development and the breakthrough of digital technology. In the future, there might therefore be reasons for revising the theories on the importance of location for the development of society.

In the context of regional economic effects of ERS production, these theories will to a large degree explain the differences between regions in size and structure of spin-off and indirect effects. Size and density will vary between the alternative regions and so will the total economic effects.

Description of the Raps model

Calculations of the effects on the economy have been done with the Raps model. Raps (*Regional Analysis and Prognosis System*) is a tool for regional planning. The system consists of statistics and models for analysis as well as long and short-term forecasting. The model is made up of five modules that mutually affect each other. The data in the model are located in a database with a large array of variables for each module. Forecasts and scenarios can be constructed by applying parameters of statistically significant connections between variables in the modules. It is possible to manually add events or shocks to the regional economy, such as a large investment or a shutdown and analyse the wider economic effects.

The model is driven by the demand directed at the regional economy from household consumption, investment, net export and input deliveries between industries. The core consists of regional input-output tables, based on official data from Statistics Sweden. The model is based on assumptions on macroeconomic and demographic development from the National Institute of Economic Research and Statistics Sweden.

One of the main purposes of the Raps model is to study the wider economic effects of shocks on the economy. By adding an exogenous activity – i.e. something that is not predicted by the basic assumptions of the model – there will be a change in the demand for input products for that activity. For example, if a new manufacturing plant is established in a region, that production plant will have an increased demand for input products necessary for its activity. The connections in the input-output tables at the core of the model will calculate what input products and to what extent. The output will be an increase in economic activity not only from the new facility itself but also from the supply chain.

Usually, these effects are designated as *direct* and *indirect* effects. The direct effects are the actual new establishment or shutdown. The indirect effects are the change in demand for input products from the supply chain in supporting industries. In this case, the direct effects will be the manufacturing of ERS elements and the construction of the ERS network. The indirect effect will appear in the supply chain of input products and services necessary to produce the elements and construct the ERS network.

Model assumptions

Based on the estimated required materials in tons per km, and adjusted by the assumptions of import quotas, the total production value of the construction of the ERS elements per each technology has been calculated by national input-output tables. The input-output tables describe the relation of each input product to the total production value for all industries. In this case, it is NACE C27 (Manufacture of electrical equipment) that applies for all four technologies. Since the mix and amount of required materials vary between the technologies, the total production value per km ERS will also vary. Hence, they will give rise to different economic effects.

As no decision has yet been made on the construction of ERS, the only guideline in terms of timeframe is the proposal for a deployment plan from the Swedish Transport Administration. In these calculations, this include steps 1 to 4 with a total of approximately 2 400 km to 2035. With no other information available, it has been assumed that the manufacturing of the ERS elements is evenly distributed over the years starting in 2023.

The main focus of the calculations is the manufacturing of the ERS elements. The effects of the construction of the ERS network with those elements are much more challenging to calculate, as there is little to no data to go on. However, based on somewhat comparable infrastructure projects and calibration with the initial total cost estimates made by the Swedish Transport Administration, a tentative calculation of the economic effects of the construction of the ERS has been made. The results must however be interpreted cautiously.

Results of calculations

What is presented below as results are the *additional effects* on the economy compared to a scenario where no ERS elements are being manufactured and no network is being constructed.

Effects are presented as employment (i.e. number of jobs) and as addition to GRP (Gross Regional Product), the regional equivalent to GDP (Gross Domestic Product), which is the sum of all goods and services produced during a year.

The *direct effects* are the number of jobs or the addition to GDP from the actual manufacturing of ERS elements. The *indirect effects* are the additional employment or GDP increase resulting from the increased demand for input products through subcontractors in the supply chain for the ERS element manufacturing.

In Figure 23, Figure 24 and Figure 25, the total employment effect (both direct and indirect) is presented for each of the three alternative regions, divided by ERS technology. For all of the regions, it is the Electreon technology that creates the most jobs, since the required materials are the most expensive. This is followed by the Siemens eHighway solution, Elonroad and finally Evias. More expensive input products mean a higher production value, which translates into greater job creation.

The production costs have been distributed evenly over the period from 2023 to 2035. However, a basic macroeconomic assumption integral to the model is increased productivity. This means that over time every employee will produce more. As the production value of manufacturing ERS elements is assumed to be equal every year, fewer employees are required as time goes by. Hence, the number of jobs created will gradually decrease.

Productivity also varies between the different regions. High productivity means fewer jobs created from the same total production value. As seen in Figure 23, Figure 24 and Figure 25, Stockholm county has the highest productivity, and Västerbotten county has the lowest. In 2023 the total number of jobs created from manufacturing ERS elements with the Electreon technology amounts to about 700 in Stockholm county. Productivity is slightly less in Västra Götaland county, where the same technology is calculated to generate about 750 jobs. In Västerbotten county, the equivalent number is 900 jobs. The ratio between regions is the same for the other technologies.

Increased productivity means that the number of jobs annually decreases. From 2023 to 2035 the employment effect from the Electreon technology is calculated to drop from 700 to 530 in Stockholm county, equivalent to about 25 per cent fewer jobs. The drop in total employment effect is even steeper in Västerbotten county, where the number of jobs decreases from 900 to 629 with the Electreon technology, which translates to more than 30 per cent. The increase in productivity is equal for all the proposed technology, which means that the relative decrease in the number of jobs is the same.

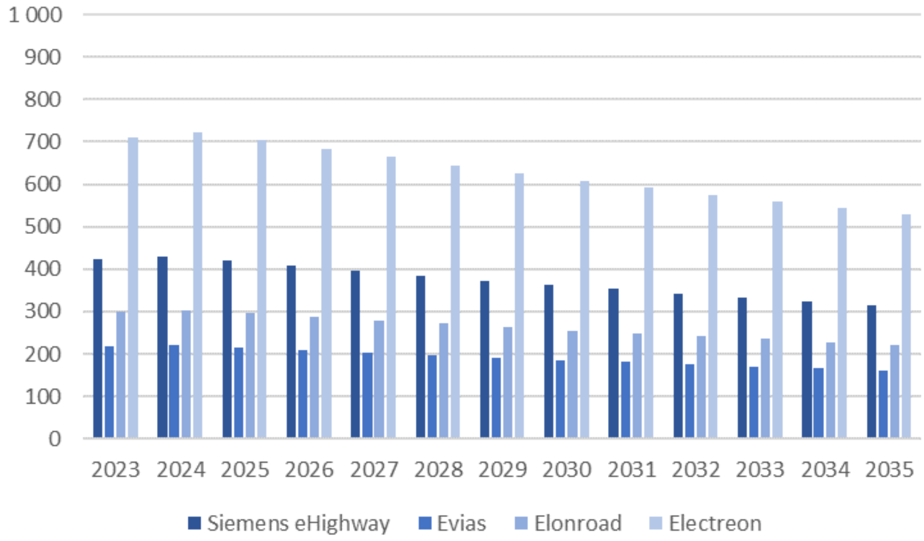


Figure 23. Total employment effect from manufacturing of elements, divided per ERS-technology in Stockholm county

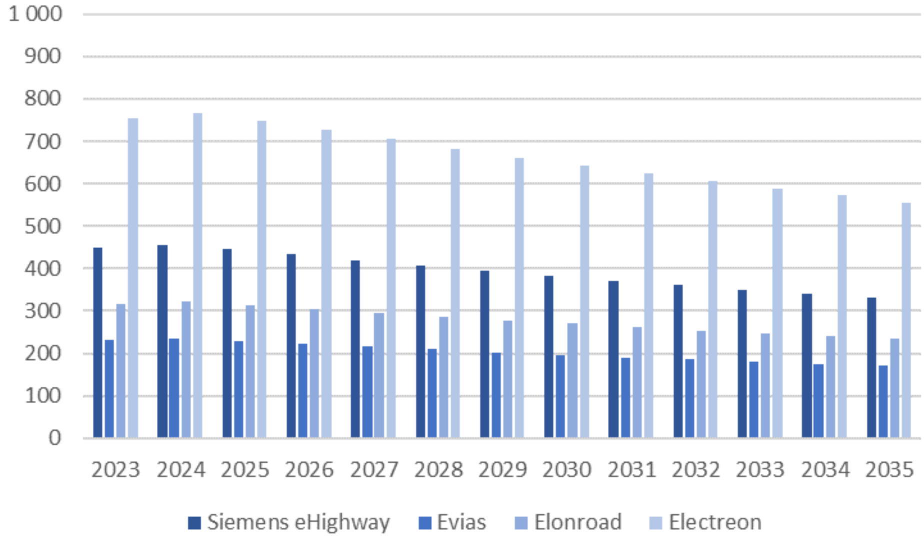


Figure 24. Total employment effect from manufacturing of elements, divided per ERS-technology in Västra Götaland county

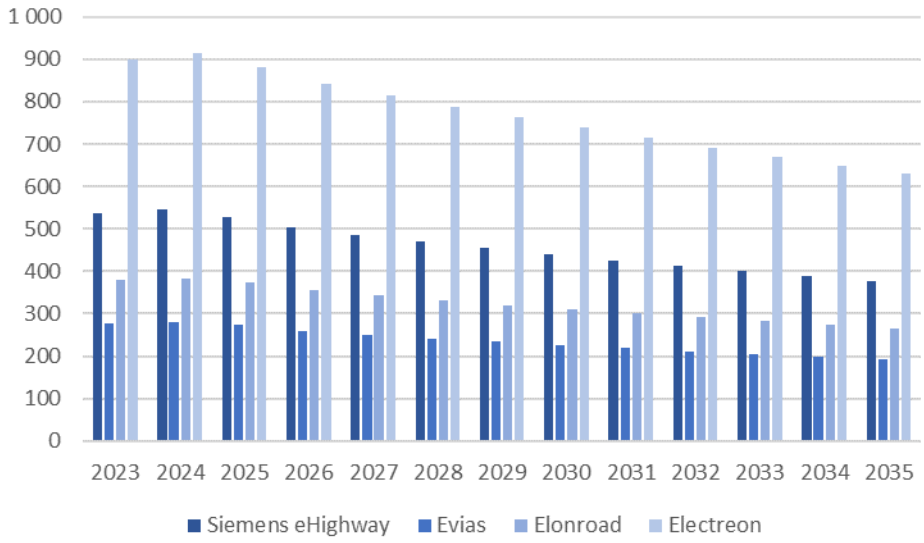


Figure 25. Total employment effect from manufacturing of elements, divided per ERS-technology in Västerbotten county

The total employment effect consists of direct and indirect effects, the direct effect being the jobs manufacturing the ERS elements and the indirect effect being the additional jobs created by increased demand for input products in the supply chain. How many additional indirect jobs that are created by the direct effect can be expressed as employment multipliers, presented in Table 24 below. The multiplier describes what the total employment effect from one direct job is. For example, a multiplier of 1,5 means that one job manufacturing ERS elements generate 0,5 additional indirect jobs, to a total effect of 1,5 jobs.

The size of the multiplier is equal for all four proposed technologies since they are treated as the same NACE industry in the model calculations. However, the multiplier varies over time and between regions. Differences between regions are explained by the size of the region and the industrial structure. A larger region – in accordance with the underlying theoretical framework – can supply necessary input products to a larger degree than smaller regions, and hence indirect jobs are more likely to be created there. In smaller regions, input product has to be imported from abroad or from other parts of Sweden. Indirect jobs will therefore be fewer in that region. The industrial structure is also an important factor. If the regional economy is specialized in industries supplying input products to the direct jobs, then more indirect jobs are likely to be created.

As seen in Table 24, the multipliers increase over time, meaning that for every job manufacturing ERS elements, more indirect jobs are created as time goes by. This can be explained by two factors. First, different industries have different increases in productivity. While the total demand for input products will be constant in monetary terms, this will translate to different rates of demand for labour. If the productivity in the manufacturing of ERS elements increases faster than the productivity in the industries supplying the input products, there will be more indirect jobs in relation to the direct jobs over time. The other factor – which will have slightly less effect – is changes in industrial structure over time. If the economy develops into a structure with more focus on industries supplying input products, less import will be needed, and more indirect jobs will be created in the region.

The multipliers (the total employment effect from one direct job) in Stockholm and Västra Götaland counties increase from 1,51 to about 1,65 between 2023 and 2035. This means that for each job manufacturing ERS elements in those regions, another 0,65 indirect jobs are created in the supply chain in 2035. In Västerbotten county the multiplier is smaller, mainly due to the region being smaller and less dense. The multiplier increases over time from 1,25 to 1,28, meaning that the number of indirect jobs created is about half of those created in the larger regions.

Table 24. Employment multipliers by region and year.

Year	Stockholm county	Västra Götaland county	Västerbotten county
2023	1,51	1,51	1,25
2024	1,53	1,53	1,26
2025	1,53	1,53	1,25
2026	1,54	1,54	1,24
2027	1,55	1,55	1,24
2028	1,56	1,57	1,25
2029	1,58	1,57	1,25
2030	1,59	1,58	1,26
2031	1,60	1,59	1,26
2032	1,61	1,60	1,27
2033	1,63	1,62	1,27
2034	1,64	1,63	1,28
2035	1,65	1,64	1,28

Manufacturing of ERS elements is – of course – located in the manufacturing industry. The indirect effects, however, are dispersed over several different industries in all parts of the economy. Figure 26 Figure 27 and Figure 28 display the relative average distribution of employment effects by industry for the three regional scenarios. As per the multipliers, the distribution is the same for all four proposed technologies.

The direct effect – the actual manufacturing of ERS elements – constitutes about 60 per cent of the employment effect in Stockholm and Västra Götaland counties and is located to the manufacturing industry. In Västerbotten county the indirect effects are relatively smaller, and the direct effect is therefore nearly 80 per cent of the total effect.

The indirect effects are mainly located to various forms of services. The majority are found within business services, such as finance, consultancy, marketing and R&D. This constitutes about 10 per cent of the total employment effect in both Stockholm and Västra Götaland counties. Trade (wholesale and retail) is another major indirect industry as well as other various services, accommodation and food services and transport. Västerbotten county differs somewhat from Stockholm and Västra Götaland counties, but not significantly.

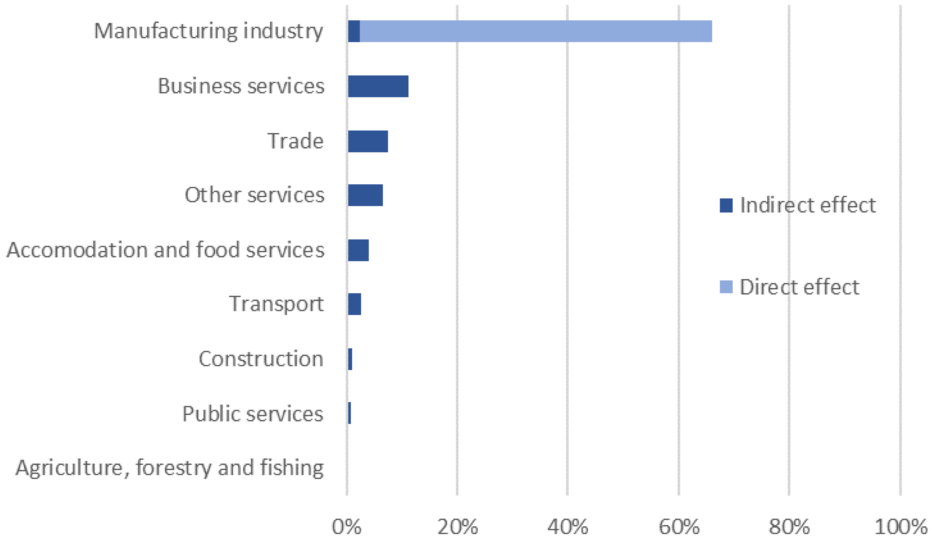


Figure 26. Employment effect from manufacturing of elements by industry, average distribution 2023-2035, direct and indirect effects in Stockholm county.

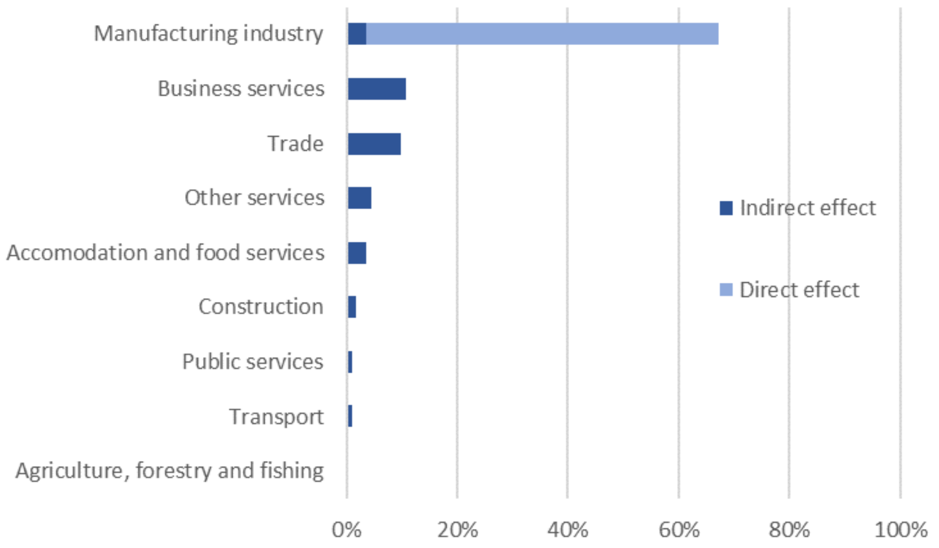


Figure 27. Employment effect from manufacturing of elements by industry, average distribution 2023-2035, direct and indirect effects in Västra Götaland county.

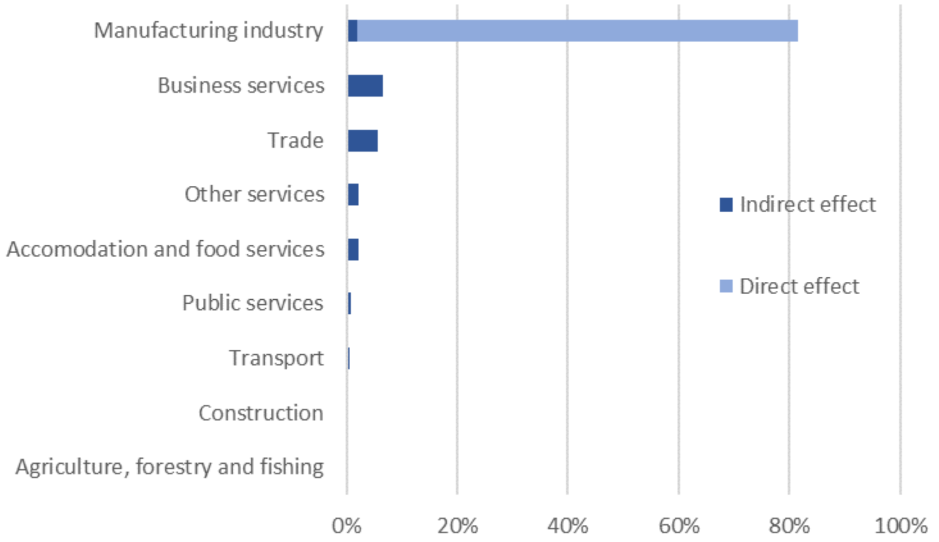


Figure 28. Employment effect from manufacturing of elements by industry, average distribution 2023-2035, direct and indirect effects in Västerbotten county.

Another way to express the economic effects of ERS investments is addition to Gross Regional Product (GRP), the sum of value added for all products and services produced during a year. In Figure 29 through Figure 31 the addition to GDP compared to the basic scenario with no ERS investment are summed up for all the years 2023-2035, per technology and region.

In both Stockholm and Västra Götaland counties, the accumulated GRP addition amounts to about 11 billion SEK for the Electreon technology, down to about 3,5 billion SEK for the Evias technology. In Västerbotten county the GRP addition is slightly smaller, for the same reasons that the employment effect is smaller.

The direct effect in GRP terms is the same across regions since it is calculated as the sum of value added, which in turn is a fixed ratio of total production value. Differences between regions consist instead of differences in indirect effect. Indirect addition to GRP is greatest in Stockholm county, with a GRP multiplier of 1,48 for the accumulated result. This means that every SEK of addition to GRP through the direct manufacturing of ERS elements, another 0,48 SEK is created through indirect effects. The corresponding multiplier for Västra Götaland county is 1,38 and for Västerbotten county 1,24.

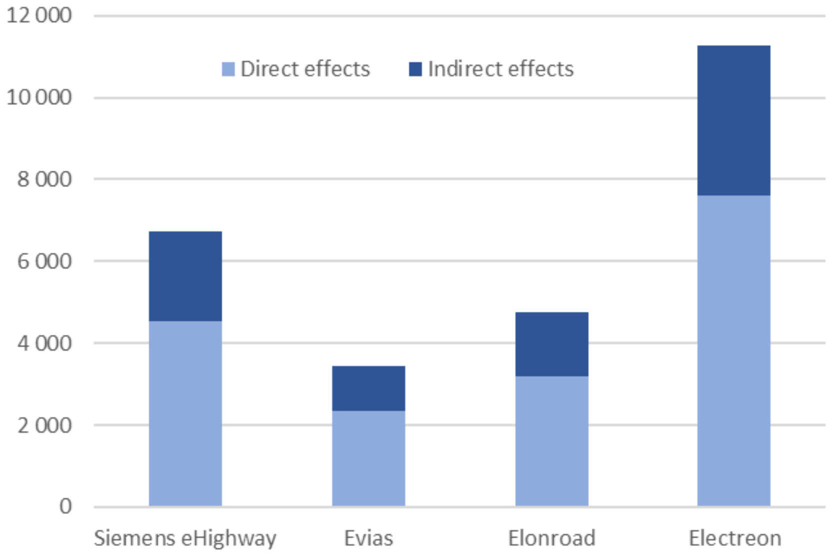


Figure 29. Total effect on GDP (million SEK) from manufacturing of elements 2023-2035, divided per ERS-technology in Stockholm county

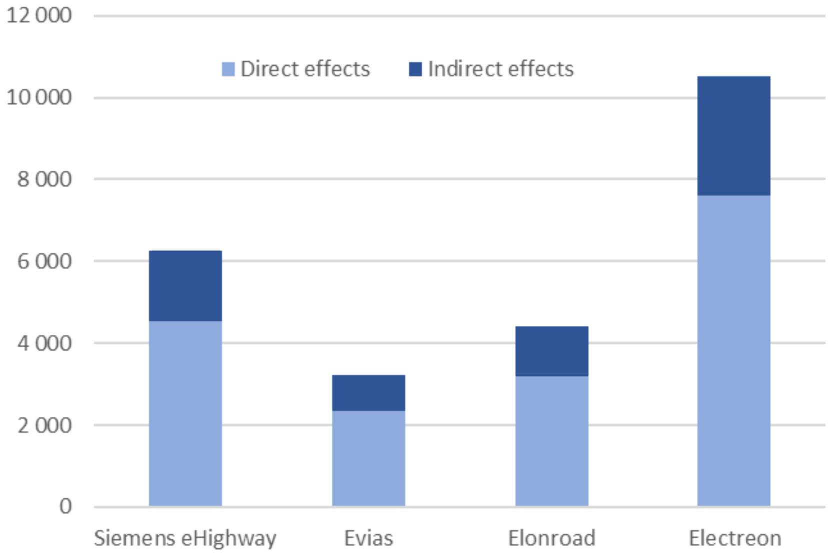


Figure 30. Total effect on GDP (million SEK) from manufacturing of elements 2023-2035, divided per ERS-technology in Västra Götaland county

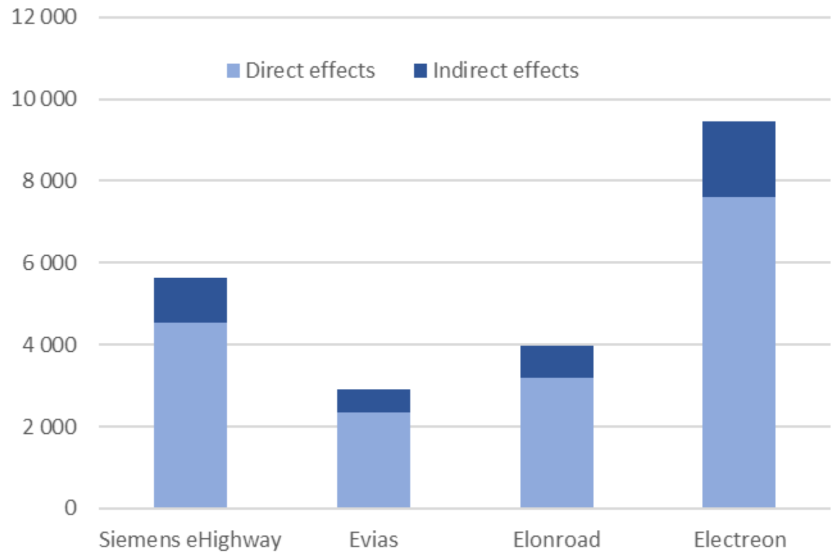


Figure 31. Total effect on GDP (million SEK) from manufacturing of elements 2023-2035, divided per ERS-technology in Västerbotten county.

In addition to economic effects from the manufacturing of ERS elements, economic effects can be expected from the actual construction of the ERS network. There is little data to base those calculations on, but tentatively rough estimates have been made, partially from comparable infrastructure projects and partially from the preliminary cost estimates from the Swedish Transport Administration.

The economic effects will appear in the regions where the ERS network will be built, but the extent of how many jobs will be created is relatively uncertain. In Figure 32, the total number of jobs by year from the construction of ERS is presented, divided by direct and indirect effects. Although the total number of jobs created is more than those generated by the manufacturing of ERS elements, it needs to be pointed out that these are the sum of the total effect for all regions affected. For each separate region, the number of jobs will be smaller, depending on the deployment step.

The multiplier for construction is also smaller than those for manufacturing, as it is a more staff-intensive industry and requires fewer input products. The multiplier varies from about 1,3 to 1,22 between years, depending on which region where the deployment takes place.

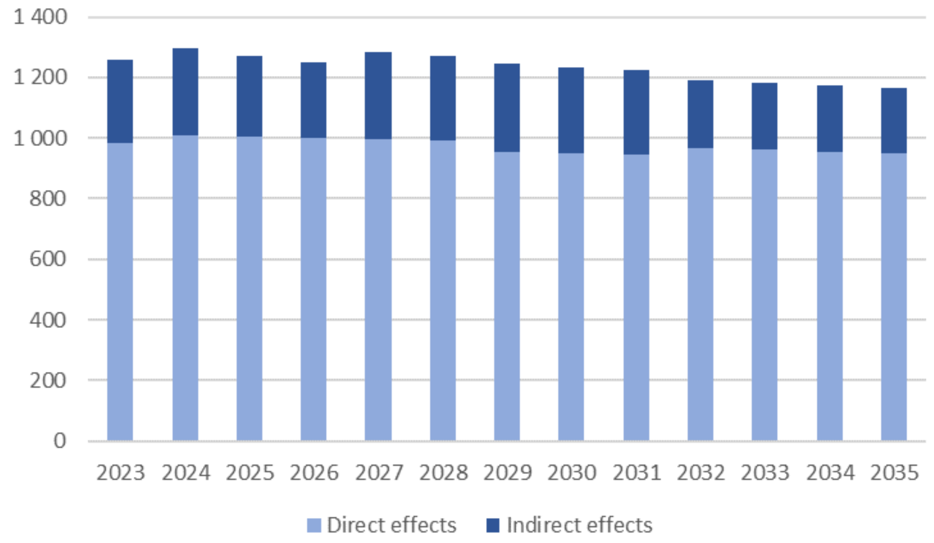


Figure 32. Total employment effect from ERS-construction in all regions of proposed network

Most of the employment effects are located to the construction industry (nearly 80 per cent), with roughly 10 per cent generated in business services and another 4 per cent in trade see Figure 33.

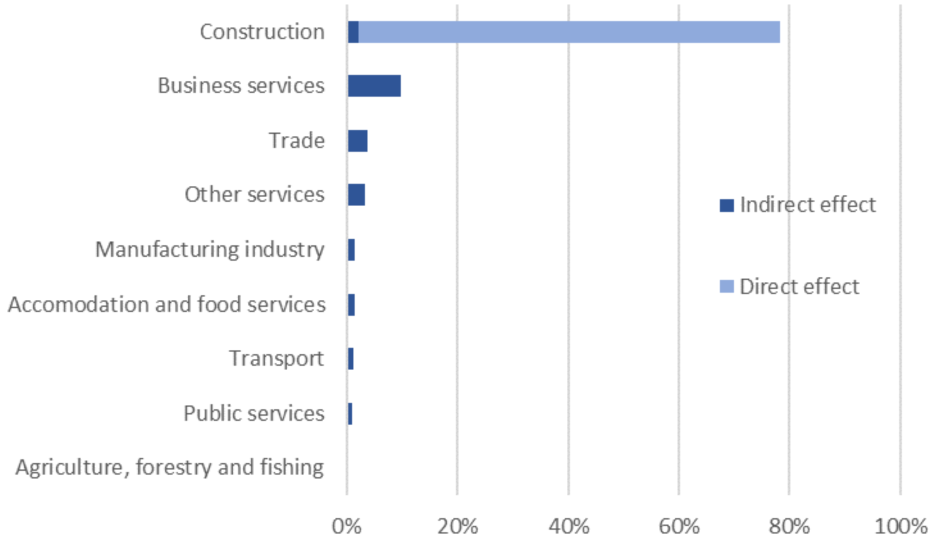


Figure 33. Employment effect from ERS-construction in all regions of proposed network by industry, average distribution 2023-2035.

Expressed as addition to GRP accumulated for the entire period 2023-2035 (see Figure 34 below) a preliminary distribution between regions has been made, based on the location of the proposed ERS network. Just as results for construction in general, this distribution must be interpreted cautiously, as there are uncertainties in underlying data and assumptions.

Accumulated for all years, the addition to GRP adds up to about 27 billion SEK. Västra Götaland and Stockholm counties are expected to receive the most parts with 5,5 and 4 billion SEK respectively, as relatively large parts of the proposed network will be located there.

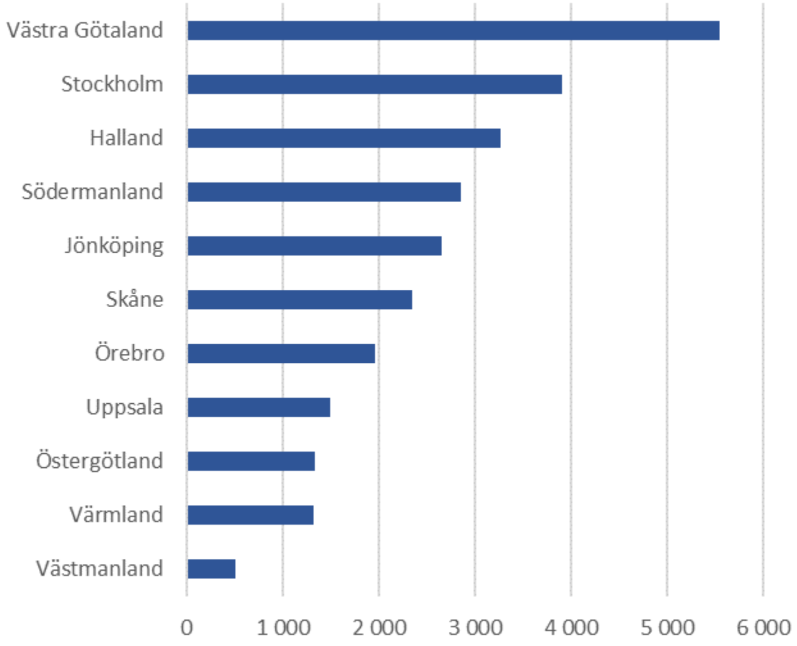


Figure 34. Total effect on GDP (million SEK) from ERS-construction in all regions of proposed network, sum for 2023-2035.

The results presented in this section cover calculations on the effects of the manufacturing and construction of the proposed ERS network. It does not cover the effects of changes in traffic accessibility as a result of the completed network. This kind of analysis usually covers so called Wider Economic Benefits, which can be connected to enlarged functional labour markets. In turn, these generate economies of scale, increase specialization and improve labour market matching. With better accessibility follows increases in employment and income.

The proposed ERS network does not however increase traffic accessibility to any significant degree. It is constructed on or in close proximity to existing road networks. The benefits of ERS do not include the traditional effects of infrastructure investments. Therefore, the calculations of the economic effects are limited to the manufacturing and construction of the network and its components.

Summary

In conclusion, depending on the choice of technology and the location of production of ERS elements, between 420 and 900 jobs can be expected to be created initially. Due to increased productivity, this number of jobs will decline over time, while total production will remain the same. This would correspond to at most 0.1 per cent of the total labour market in Stockholm and Västra Götaland counties and 0.7 per cent of the labour market in Västerbotten county.

The economic impact in terms of addition to GRP equals between 240 and 870 million SEK, which corresponds to between 0.1 and 0.6 per cent of total GRP in the regions. The effects appear during the times the investments are made, no calculations of long time effects are made. Accumulated for the entire period, the total addition to GRP amounts to between 3.5 and 11 billion SEK, depending on the technology. Total cost of production – based on estimates of cost per km from the Swedish Transport Administration and the proposed network of 2400 km – amounts to between 30 and 50 billion SEK, suggesting a return to the regional economy of around 10-20 per cent.

For every job created producing ERS elements, between 0.2 and 0.5 additional jobs are created through indirect effects at subcontractors. The effects are expected to be largest in Stockholm and Västra Götaland counties, due to higher productivity and generally larger size of the labour markets.

The employment effect will appear primarily in the manufacturing industry, but a majority of the indirect effects are expected to appear in business service sectors and trade.

Worth emphasizing is that the jobs calculated to be created are temporary for the period of constructing the ERS network. They do not include effects due to changes in traffic accessibility.

WP 5 Swedish Prerequisites for BET and FCET

Introduction

This chapter examines two alternatives to ERS: Battery Electric Trucks (BETs) and Fuel Cell Electric Trucks (FCETs). They are examined in the Swedish context, focusing on how their developments have affected the Swedish path choices regarding ERS. The examination is mainly based on existing analysis from central Swedish stakeholders. The purpose is to give a picture of the Swedish situation as well as the background to decisions taken, with ERS in perspective. Hence, this chapter differs from the rest of the report in that our German project partners are the main recipients of the text. The findings from this analysis have also given input to the technology assessment reported in the texts about WP 2.

The chapter starts off with a general description of the Swedish policy choices, whereafter it describes recent developments within BETs and FCETs.

Swedish Policy Choices

This section summarizes mainly two reports from the Swedish Transport Administration: one on ERS (Trafikverket, 2021) and one on stationary charging (Trafikverket, 2021).

As a result of the rapid development of the battery sector, the proportion of heavy traffic expected to use the electric roads in Sweden has decreased considerable last years and is now at a level of in best case 25% (Trafikverket, 2021). The results from the socio-economic analysis made by the Swedish Transport Administration (Trafikverket, 2020) show that it is socio-economic profitable with an expansion of electric roads in Sweden only if the admixture of biofuels is kept low and the incentives for using the electric roads are good (high diesel price, low user fee).

The announced Swedish policy regarding biofuel admixture in the existing fossil fuel mix is planned to increase steadily from the year 2020 to 2030 for both gasoline and diesel (Regeringen, 2019):

Table 25. Announced Swedish policy regarding biofuel admixture.

Year	Gasoline (%)	Diesel (%)
2020	4,2	21
2030	28	66

Based on this, the Swedish Transport Administration has concluded that it is very uncertain if the traffic volumes on the Swedish road network are sufficient for a socio-economically profitable expansion of ERS (Trafikverket, 2021).

ERS or other non-ERS alternatives could however still play a crucial strategic role in the long term if they can facilitate a reduced total demand of biofuel for the road transport sector, which instead then can be allocated to other sectors where electrification is not as feasible.

The Swedish Transport Administration finds that a high increase of biofuels admixture in the existing fossil fuel mix is the most cost-effective policy means to reduce emissions in the transport sector (excluding high carbon price to reduce transports). The share of the traffic that will use the electric road in the future is affected not only by financial incentives but also by the development of alternative solutions (such as BET and FCET). Results from the Swedish Transport Administration's analysis show that it is possible to achieve a comprehensive reduction in the amount of climate emissions from heavy vehicles by combining different measures over time, specifically if the admixture of biofuels is increased. Hence, the Swedish Transport Administration estimates that in the short term, a combination of increased shares of biofuels in the fossil fuel mix and an increase in stationary charging is an effective measure to reduce emissions of heavy transport (Trafikverket, 2021). The Swedish

Transport Administration concludes that the technical development for alternative solutions to ERS, therefore, needs to be regularly monitored as basis for investment decisions.

According to The Swedish Transport Administration, ERS could in the longer term contribute to reducing emissions by between 9-18 percent of the total emissions from heavy traffic in 2040, with a low level of admixture of biofuels. At a higher level of the admixture of biofuels, the potential is naturally significantly lower and the corresponding reduction in emissions is between approximately 3-7 percent of the total emissions in 2040.

The climate benefits of a large-scale expansion of electric roads are therefore less than the overall target of emission reductions. The reasons for the moderate effects compared with the initial expectations are e.g. lowered expectations on the number of vehicles using the electric road, mainly due to BET becoming introduced in the market and takes shares in local and regional transports (Trafikverket, 2021).

As the fleet of existing fossil fuel trucks reduces in numbers, the aggregated demand for fossil fuels used by heavy trucks will be reduced. Although the admixture of biofuels is increasing, the reduced number of fossil fuel trucks will still be on an aggregated level over time enabling biofuels to be released to other sectors that are more difficult to electrify. Recent developments within biofuel production in the Nordics show that it is possible to produce the required amounts of biofuel in a sustainable way within the Nordic countries (Wråke, 2021). In the coming years, also electro fuels are expected to be used as one part of the biofuels mix (Natanaelsson, 2021). According to the Swedish Transport Administration, ERS and FCETs are as of today considered as complementary technologies to the BETs, which is foreseen to drive the market development of electrified trucks (Natanaelsson, 2021).

Battery Electric Trucks (BETs)

According to the Swedish Transport Administration, it is possible to achieve up to 85 percent of greenhouse gas emissions reduction from heavy vehicles in Sweden through a combination of stationary charging and a gradually higher proportion of renewable fuels in the existing fuel mix (Trafikverket, 2021).

A higher admixture of biofuels is assumed to increase the price of fossil fuels. A higher fuel price is assumed to reduce the forecasted increase in road traffic. The higher fuel price will also lower the break-even point for profitability to switch energy source from diesel to electricity and increase the driving force to improve efficiency of their operations. A low admixture of biofuels, and thus lower cost development for fuels, provides significantly lower incentives for a development of stationary battery charging that is business-economically profitable without extensive government support. In addition to a powerful reduction of greenhouse gases, electrification through stationary charging of heavy vehicles can also reduce emissions of other air pollutants, including exhaust particles and noise (Trafikverket, 2021).

Forecasts of the development of electrified heavy trucks in Sweden

There are currently strong driving forces for electrification with stationary charging of heavy trucks. The heavy truck fleet today consists of approximately 84,000 vehicles registered in Sweden. By the year 2040, heavy road transport is expected to increase by about 43 percent, according to the Swedish Transport Administration's forecasts. This means that the number of heavy vehicles is expected to increase to approximately 120,000 by 2040. Increased efficiency of logistics chains, intermodality and urban planning can to some extent dampen this traffic development (PowerCircle, 2021).

The division between local, regional, and long-distance transports are shown in Table 26.

Table 26. The Swedish truck market. Source: (PowerCircle, 2021).

	Local transports	Regional transports	Long distance transports
Total weight (ton)	3,5-16	16-30	30-
Number of trucks in traffic (2019)	~ 18 000	~ 53 000	~13 000
Share (%)	21	63	16
Daily distance (km)	150–200	300–400	400–600
Yearly distance (km)	<50 000	50 000-1000 000	>100 000
Energy (kWh/km)	0,5–1	1–1,5	1,5–2
Typical of operations	General cargo Food deliveries Garbage collection	General cargo Food deliveries Fuel transport	General cargo Food deliveries Fuel transport

According to the Swedish Transport Administration, the number of electric trucks over 3.5 tons that use stationary charging in Sweden is assumed to amount to over 70,000 individual vehicles by 2040. Electrification of heavy vehicles through stationary charging increases the demand for batteries, and regarding the foreseen increase of batteries, a focus on conservation of natural resources is required. In this context, it is positive that the EU and the battery industry seem to have a common view that the reuse of strategic metals included in batteries soon should be driven towards a level of 90-95 percent.

At the end of 2021, there were approximately 69 Swedish registered heavy electric trucks in the country (Elbilsstatistik, 2021). The market of electrified heavy trucks is at the moment still in an initial stage, but the development goes very fast, and new truck models for stationary charging is continuously entering the market.

According to Power Circle (based on input from several truck manufacturers), the models for shorter daily trips will be electrified first, e.g. garbage collection etc, whereafter electrified truck models for longer transports will be developed, according to Figure 35.

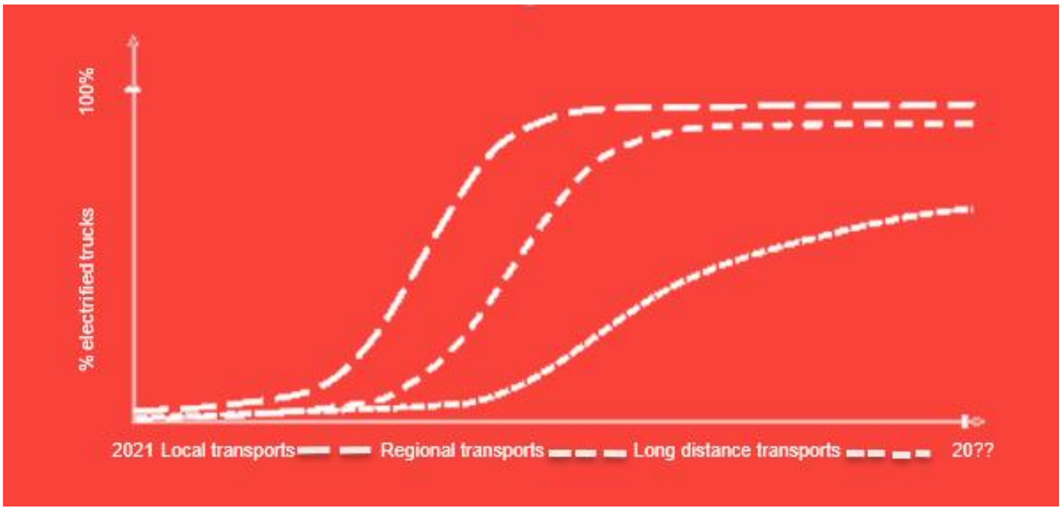


Figure 35. Foreseen development of the electrification of trucks. Source: PowerCircle (2021)

Today there are already heavy truck models out on the market that supports most of the needs for local transports and partly also regional transports. As an example, Scania's electric 29-ton truck can be ordered with a 300-kWh battery that can reach up to 250 km, and Volvo's 44-ton truck can be installed with a 540-kWh battery that can reach up to 300 km (PowerCircle, 2021).

For long-distance transports, the strategies from the manufacturers differ. Volvo Group as well as Daimler Trucks believe in a combination of fast charging electric trucks and fuel cells. Scania continues look at both FCET, BET and ERS (PowerCircle, 2021).

Charging infrastructure

According to Power Circle, the lack of infrastructure for stationary charging today constitutes an obstacle to the electrification of heavy trucks, and more effective action is required to improve the publicly accessible refueling and recharging possibilities. Stationary charging of heavy vehicles is the most mature technology for the electrification of heavy trucks, as vehicles in weight classes up to 60 tons are available on the market, primarily for local and regional distribution (PowerCircle, 2021).

The structure needs to consist of charging with lower power at depots or other places where the vehicles stand still for longer periods (so-called depot-charging), at destinations where the trucks still stop during a work shift such as logistics centers (so-called semi-public charging) and public fast charging with higher effects along major roads and at other strategically selected points. The need for stationary charging for heavy trucks will increase as the number of electric trucks in the market increases (PowerCircle, 2021).

As BETs for local and regional distribution are already on the market in Sweden and in other countries, the Swedish Transport Administration has suggested that it is reasonable to invest primarily in the expansion of infrastructure for stationary charging for heavy vehicles in local and regional distribution in short term. In addition, research, development, and demonstration of all technologies for electrification for long-haul distribution are suggested to continue in the coming years to assess how the conditions develop. According to forecast scenarios made by the Swedish Transport Administration, only a minor part of the long-haul distribution is expected to utilize stationary charging up till 2030, corresponding 15 percentage of the fleet size, but will be ramped up to 50 percentage of the fleet size until 2040. Local distribution will have the most rapid ramp up, closely followed by regional distribution, see Table 27 (Trafikverket, 2021).

Table 27. Estimated percentage of fleet size that will utilize stationary charging.

Type of distribution	2030	2035	2040
Local	50%	60%	75%
Regional	30%	50%	75%
Long-haul	15%	30%	50%

The introduction of electrified heavy trucks is today in a very early stage, hence very few charging points exist. According to Power Circle, 350 charging points will be built by 2025 and 1200 by 2030. A comprehensive system for stationary charging provides the conditions for a flexibly distributed investments of infrastructure as it can be expanded with charging stations in stages and in the geographical areas where a need exists. Such more locally developed geographical coverage areas can eventually be built together and expanded (PowerCircle, 2021).

One example of a charging point is the energy company Göteborgs Energi that has installed a fast charger on 175 kW in Gothenburg, on the Swedish West Coast. The charger has so far mainly been used by taxis and passenger cars as only two electric trucks are rolled out on the streets of Gothenburg, but this is expected to change as more trucks are electrified. Several actors are planning for the expansion of public charging infrastructure, both other energy companies and fuel distributors such as Circle K and OKQ8. Circle K has recently prepared for a public charging station with 40 places for trucks in one of its stations in the Gothenburg area (PowerCircle, 2021).

In the Swedish transport system today (2021) there are over 150,000 rechargeable passenger cars, of which at least 50,000 are fully electric. The power supply to these vehicles takes place through stationary charging and does not require any further legal adaptation, change of the road system or monitoring and control. Stationary loaded heavy vehicles are not considered to change this situation. Permit processes for building supplementary electricity networks up to charging stations do not constitute a legal obstacle but may need to be reviewed to speed up the process and thereby facilitate a rapid electrification of heavy vehicles (Trafikverket, 2021).

In order to achieve fast and powerful electrification via stationary charging in Sweden, in addition to the higher fuel price obtained with a high admixture of biofuels, the Swedish Transport Administration has stated that additional incentives and instruments are needed. However, with faster rising prices for fuel (with for example the admixture of biofuels), they forecast that stationary charging can be economically profitable in Sweden until the year 2035 without additional state support. State supports up to this point can take the form of increased fuel prices, an environmental truck premium or support for the construction of charging infrastructure for stationary charging (Trafikverket, 2021).

Moreover, the expansion of required charging points would initially need to have some form of financial support to accelerate the electrification of heavy vehicles according to the Swedish Transport Administration. Hence, a financial support corresponding to up to 50 percent of the investment cost is assumed to be sufficient up to year 2030. From 2035, there are conditions for commercial roll-out without additional government support. For this, a total state support of up to SEK 6.5 billion would be required until the year 2030 according to their estimates. Such support would make it possible to electrify a significant part of the heavy road traffic with a significantly higher climate benefit and lower cost than other electrification alternatives, for example, ERS according to the Swedish Transport Administration (Trafikverket, 2021)

The Swedish Transport Administration has stated that there is a large potential for electrification of heavy vehicles. For the case of ERS, the choice of technical systems must be standardized and developed in collaboration with the rest of the EU and, ideally, the rest of the world. For stationary charging, this is not considered to pose a significant risk as stationary charged heavy vehicles, primarily for local and regional distribution, are already on the market in several countries. CEN and CENELEC[15] state in the work programme for 2022 that standards are important to support EU directives, such as the AFI-directive (CEN & CENELEC, 2021). Previous work within CENELEC has taken railway standards as points of departure for developing ERS standardization (see Jöhrens et al (2021)). Other forms of electrification are considered to have greater risks in this respect. Especially for electrification of heavy vehicles that are used over larger areas, have longer driving distances or have a higher energy requirement, technological development is more uncertain.

Battery Production

Manufacturing batteries for all BEV’s is of course a challenge. However, Sweden is expected to emerge as a regional outperformer for EV battery manufacturing, with domestic producer Northvolt establishing itself as a regional leader in the manufacturing of EV batteries, aiming to develop 150GWh across Europe by 2030, with its domestic market set to be a major host of this capacity. In June 2021, Northvolt and Swedish automaker Volvo announced a partnership to construct a battery manufacturing facility with a 50GWh capacity. The facility is expected to enter into production in 2026 and will produce batteries exclusively for Volvo. VW Group is similarly involved with Northvolt for its EV battery supply chain, having signed a production deal in 2019. VW Group announced in June 2021 a EUR 500mn investment in Northvolt amid a EUR2.3bn private placement of funding. This will support Northvolt's efforts to expand its facility in northern Sweden that is currently under construction, from 40GWh annual production capacity to 60GWh (FitchSolutions, 2021).

---

[15] European Committee for Standardization (CEN) and European Committee for Electrotechnical Standardization (CENELEC).

Fuel Cells

Developments in fuel cells have been significant in recent years and costs are expected to fall sharply in the coming decade. Fuel cells may thus constitute a significant element in the electrification of heavy vehicles, especially heavy vehicles that are used over larger areas, have longer driving distances and have a higher energy requirement (Trafikverket, 2021).

Vehicle operation via hydrogen produced from electricity has a lower energy efficiency than using electricity directly. According to the Swedish Transport Administration, this does not have to be a problem, depending on how the hydrogen is produced and what role the hydrogen has in the energy system. The big challenge is to be able to produce green hydrogen at a competitive price (Trafikverket, 2021).

Today, most of the industrial hydrogen in the world as well as in Sweden is generated from fossil fuels as natural gas, methane, or coal. “Green” hydrogen is made by splitting water using electrolysis powered by renewable energy. “Blue” hydrogen is derived from natural gas with the resulting CO_2 captured and stored. Only the green hydrogen is zero-carbon. Natural gas accounts for less than 2.5% of the energy mix of Sweden, why it will never become a major source of hydrogen in the country.

Hydrogen as a fuel for heavy road transport requires trucks equipped with fuel cells, although attempts to run internal combustion engines with hydrogen are also underway. An advantage of fuel cell trucks, which are often lifted in comparisons with battery-powered trucks, is longer range. Another advantage is short refueling time. Several truck manufacturers have launched investments in fuel cell trucks (Trafikverket, 2021). Hyundai Hydrogen Mobility is the first out to commercialize fuel cell heavy-duty trucks and has been shipping out its first ten units to Switzerland. The plan is to roll out another 1650 units by 2025 (Hyundai Hydrogen Mobility, 2020).

A necessary condition for hydrogen as a fuel is the expansion of filling stations. There are some plans to expand filling stations in Sweden and the development is expected to be affected by decisions at the EU level. In July 2021, a proposal came from the EU that, among other things, the Member States should ensure the expansion of hydrogen tank infrastructure along major roads with an interval of 150 km in 2030 (Trafikverket, 2021).

In the report from 2021, the Swedish Transport Administration states that they are focusing on primarily two alternative paths for the introduction of FCET’s in Sweden. One possible development for the expansion of tank infrastructure for hydrogen is that it takes place in many places at the same time to achieve a large-scale that makes the alternative attractive. Another possible expansion process is that hydrogen infrastructure (production, distribution, and filling stations) will be developed in some places at an earlier stage and that the use of fuel cell vehicles will be higher in these regions than in others. Production costs and distribution strategies determine which expansion strategy will dominate, and this can vary in different parts of the country (Trafikverket, 2021). In the Electrification Commission action plan, published in 2021-12-28, this is further elaborated (Elektrifieringskomissionen, 2021).

A very small part of the hydrogen gas produced in Sweden and globally today is fossil-free. This means that a wide-ranging expansion of the fossil-free production of hydrogen will be required for several different areas of use. The Swedish Transport Administration has identified hydrogen as having great potential also for, among other things, storage of electricity in more variable electricity production, and as input goods for the industry. Developments in these areas can be expected to affect hydrogen's opportunities as a fuel for vehicles to a large extent. Increased use in other sectors may make hydrogen more accessible, but scarcity may also occur (Trafikverket, 2021).

Production and distribution of hydrogen as a fuel can take place both centrally with the transport of the hydrogen and decentralized in connection with filling stations. These different strategies provide different cost structures where economies of scale are set against distribution costs. Something that is often mentioned as an attractive production alternative is to produce hydrogen with "surplus electricity". Excess electricity refers to the production surplus that arises at times when wind power and solar cells produce a lot of electricity at the same time as demand is low. However, the Swedish Transport Administration has concluded that it is possible to question the long-term nature of such a production strategy as the conditions in the electricity market can change over time. For example, a more flexible use of electricity, the development of other storage methods and the expansion of electricity network capacity can even out the imbalances in the electricity market (Trafikverket, 2021).

Another condition that can promote increased use of hydrogen as a fuel is if there is production or use of hydrogen for purposes other than transport in a certain region. However, it is not evident that other hydrogen use can be transferred to the transport sector, as clear incentives are required to go from being a producer and user of hydrogen in, for example, own industrial processes to using hydrogen for their transport or reselling it. Factors that play a role in the production of hydrogen include local electricity supply and the possible degree of utilization of filling stations (Trafikverket, 2021).

The Swedish Hydrogen strategy

A proposal for a new Swedish Hydrogen strategy has recently been developed and presented to the government, where fossil-free hydrogen in Scandinavia is expected to be competitive with fossil hydrogen before 2030. The proposal in the strategy is that only fossil-free hydrogen should be rewarded. Expansion of the hydrogen infrastructure in the country is suggested to be accelerated by establishing cross-sectoral local and regional hydrogen clusters (Hydrogen Valleys). They can be established where existing industries use or will use hydrogen and where infrastructure such as ports and railways already exist, see Figure 36 (Fossilfritt Sverige, 2021).

Figure 36. Potential hydrogen clusters in Sweden based on concrete plans and projects. Source: Fossilfritt Sverige (2021).

Several new hydrogen initiatives and partnerships have recently been announced, e.g.:

- HYBRIT's investment in fossil-free steel with hydrogen as a reduction agent, and LKAB's major industrialization of the same technology for carbon-free sponge-iron.
- Ovako is preparing the next demonstration step for steel heating using fossil-free hydrogen.

- Both Scania and Volvo AB invest in the development of hydrogen-powered trucks.
- Perstorp’s “Project Air”, where together with Fortum and Uniper, they are developing a unique process for sustainable methanol production by combining CCU (Carbon Capture and Utilization) and gasification.
- Preem and St1 are planning increased biofuel production using fossil-free hydrogen.
- St1, Liquid Wind and Jämtkraft are preparing for various investments in electro fuels.
- Nouryon plans to replace fossil hydrogen with fossil-free hydrogen for its hydrogen peroxide production.

According to this hydrogen strategy, today’s hydrogen projects in Sweden have the potential to achieve a reduction of 7,1 million tons of carbon dioxide per year in direct emissions by 2045. That equals 14 per cent of Sweden´s national emissions (Fossilfritt Sverige, 2021).

References

Aronietis, R., & Vanelslander, T. (2021). *Logibat WP2 Chapter: Economic Impacts of the Catenary Electric Road System Implementation in Flanders.* VIL Empowering Logistics.

Balieu, R., Chen, F., & Kringos, N. (2019). *Life cycle sustainability assessment of electrified road systems, Road Materials and Pavement Design, 20(sup1).* doi:DOI:10.1080/14680629.2019.1588771

Börjesson, M., Johansson, M., & Kågeson, P. (2020). Samhällsekonomiska kalkyler för elvägar. *No 2020:2, Working Papers from Research Programme in Transport Economics, No 2020:2*. Retrieved from https://EconPapers.repec.org/RePEc:hhs:trnspr:2020_002.

Börjesson, M., Johansson, M., & Kågesson, P. (2021). The economics of electric roads. *Transportation Research Part C: Emerging Technologies*.

Carreira da Cruz, M.-A. (2022). CEN-CENELEC, Focus area Road vehicles and alternative fuels infrastructure. (F. Widegren, Interviewer)

CEN & CENELEC. (2021). *Work programme 2022.*

CENELEC CLC/TC9X/Sec1302/CD. (2021). *prTS50712:2021 Railway applications - Current collection systems - Technical criteria for the interaction between pantograph and overhead contact lines on electrified roads.* CENELECT .

Commission Implementing Regulation (EU). (2010). *Directive 2010/40/EU of the European Parliament and of the Council of 7 July 2010 on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport Text with EEA relevance.* Retrieved from http://data.europa.eu/eli/dir/2010/40/oj

Commission Implementing Regulation (EU). (2019, 11 28). *Commission implementing regulation (EU) 2020/204 of 28 November 2019.* Retrieved 01 13, 2021, from Publications Office of the European Union: http://data.europa.eu/eli/reg_impl/2020/204/oj

Directive 1999/62/EC of the European Parliament and of the Council . (2015, 04 30). *Charging of heavy goods vehicles: Eurovignette Directive.* Retrieved from EUR-Lex: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=LEGISSUM%3Al24045b

Directive 2014/94/EU of the European Parliament and of the Council. (2014, 10 28). *Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure Text with EEA relevance.* Retrieved from EUR-Lex: http://data.europa.eu/eli/dir/2014/94/oj

Directorate General for Internal Policies. (2014). *Technology Options for the European Electronic Toll Service.* Brussels: The European Parliament's Committee on Transport and Tourism.

Drivkraft Sverige. (2019). *Drivkraft Sverige.* Retrieved from Energiinnehåll, densitet och koldioxidutsläpp: https://drivkraftsverige.se/uppslagsverk/fakta/berakningsfaktorer/energiinnehall-densitet-och-koldioxidemission/

Elbilsstatistik. (2021). Retrieved from https://www.elbilsstatistik.se/).

Elektrifieringskomissionen. (2021, 03). *Eldrivna transporter på väg: Elektrifieringskommissionens handlingsplan för elektrifiering av de mest trafikerade vägarna i Sverige.* Stockholm: Infrastrukturdepartementet. Retrieved from https://www.regeringen.se/4b0da2/contentassets/d0a474ce90c8429bbb33e9690d9de1a4/211222_handlingsplan_el_webb.pdf

Elonroad, Evias/Elways, Electreon, & Siemens. (n.d.).

Elvägsutredningen. (2021). *Regler för statliga elvägar (SOU 2021:73).* Stockholm: Infrastrukturdepartementet.

Energimyndigheten. (2018). *Omvärldsbevakning biodrivmedelsmarknaden. Promemoria rörande biodrivmedelsmarknaden i Sverige och i världen.* Energimyndigheten.

ePURE. (2020). *Overview of biofuels policies and markets across the EU-27 and the UK.*

(2019). *eRoad Arlanda L 1.6 "Final Report - Summary of Knowledge Base.*

European Comission. (2022). *Commission implementing decision of 24.3.2022 on a standardisation request to the European standardisation organisations.* Bussels: C(2022) 1710 final. Retrieved from https://ec.europa.eu/growth/tools-databases/mandates/index.cfm?fuseaction=search.welcome&lang=en

European Commission. (2021, 01 13). *EETS-European Electronic Tolling Service*. Retrieved from European Commission: https://joinup.ec.europa.eu/collection/ict-standards-procurement/eets-european-electronic-tolling-service

European Commission. (2021, 03 01). *TENtec Interactive Map Viewer*. Retrieved from Mobility and Transport: https://ec.europa.eu/transport/infrastructure/tentec/tentec-portal/map/maps.html

European Commission. (2022, 03 01). *Single Market and Standards: Key players in European Standardisation*. Retrieved from Internal Market, Industry, Entrepreneurship and SMEs: https://ec.europa.eu/growth/single-market/european-standards/key-players-european-standardisation_sv

European Union. (2018). *EUR-Lex.* Retrieved from Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources: https://eur-lex.europa.eu/eli/dir/2018/2001/oj

FitchSolutions. (2021). *Sweden To Emerge As Key Market For Electric Vehicle Charging And Manufacturing.* London, UK.

Fossilfritt Sverige. (2021). Retrieved from https://fossilfrittsverige.se/en/strategies/hydrogen/

Gustavsson, M. G., & Lindgren, M. (2020b). *Maturity of power transfer technologies for electric road systems. Proceedings of 8th Transport Research Arena TRA 2020.* Helsinki. Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:ri:diva-44423

Gustavsson, M. G., Lindgren, M., & Mottschall, M. (2020). *Real-world experiences of ERS: Best practices from demonstration projects in Sweden and Germany.* Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:ri:diva-48792

Gustavsson, M. G.; Alfredsson, H.; Börjesson, C.; Jelica, D.; Sundelin, H.; Johnsson, F.; ... & Lindgren, M. (2021). *Research & Innovation Platform for Electric Road Systems. RISE Report 2021:23.* RISE .

Gustavsson, Martin G. H., Hacker, Florian, & Helms, Hinrich. (2019). *Overview of ERS concepts and complementary technologies.* Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:ri:diva-38294

Hacker, F., Jöhrens, J., & Plötz, P. (2020). *Economic viability, environmental impact and expansion scenarios for light-duty trucks in Germany .* BOLD project.

Hartwig, M., Bußmann-Welsch, A., & Lehmann, M. (2020). *Models for the development of electric road systems in Europe. IKEM Working Paper, 2020. .* doi:DOI: 10.5281/zenodo.4327310

Hyundai Hydrogen Mobility. (2020). Retrieved from https://hyundai-hm.com/en/2020/07/08/worlds-first-fuel-cell-heavy-duty-truck-hyundai-xcient-fuel-cell-heads-to-europe-for-commercial-use/

IEA. (2021). *IEA.* Retrieved from Transport Biofuels: https://www.iea.org/reports/transport-biofuels

International Electrotechnical Commission. (2022, 03 10). *IEC everywhere for a safter and more efficient world*. Retrieved from IEC: https://www.iec.ch/homepage

International Electrotechnical Committee. (2022, 03 01). *TC 69 Scope*. Retrieved from TC 69: Electrical power/energy transfer systems for electrically propelled road vehicles and industrial trucks: https://www.iec.ch/dyn/www/f?p=103:7:0::::FSP_ORG_ID,FSP_LANG_ID:1255,25

International Organization for Standardization. (2022, 03 10). *ISO: About Us*. Retrieved from ISO: https://www.iso.org/about-us.html

Intraplan. (2014). *Fehmarnbelt Forecast 2014 - Update of the FTC-Study of 2002 .* Intraplan Consult GmbH.

ITF. (2022). *Mode choice in freight transport.* OECD/ITF.

Jang, Y. (2018). Survey of the operation and system study on wireless charging electric vehicle systems. *Transp. Res. Part C Emerg. Technol.*, 844-866.

Jourquin, B.; Beuthe, M. (2019). Cost, transit time and speed elasticity calculations for the European continental freight transport. *Transport Policy, 83*, 1-12.

Jussila Hammes, J. (2020). *Potential for reducing greenhouse gas emissions by electrifying freight transport on the Swedish E-road network.* VTI Working Paper 2020:2.

Jöhrens. (2020). *Roadmap OH-Lkw: Einführungsszenarien 2020-2030.* Heidelberg: IFEU.

Jöhrens, J., Helms, H., Lambrecht, U., Spathelf, F., Mottschall, M., Hacker, F., . . . Taljegård, M. (2021, 03 10). *Connecting Countries by Electric Roads: Methodology for Feasibility Analysis of a Transnational ERS Corridor by.* Retrieved from https://www.ifeu.de/fileadmin/uploads/pdf/CollERS_Connecting_countries_by_Electric_Roads%E2%80%9310_March_2021.pdf

Kommerskollegium. (2022, September 09). *Historiskt stor nedgång i handeln med Ryssland*. Retrieved from https://www.kommerskollegium.se/om-oss/nyheter/2022/historiskt-stor-nedgang-i-handeln-med-ryssland/

Kommittédirektiv 2022:77. (2022). *Regeringen.* Retrieved from En nationell bioekonomistrategi – ett verktyg för den gröna industriella omställningen: https://www.regeringen.se/rattsliga-dokument/kommittedirektiv/2022/06/dir.-202277/

Miglianico, D. (2022, 02 28). Secretary at CLC/TC 9X, CEN-CENELEC. (F. Widegren, Interviewer)

Natanaelsson, K. (2021, 11 08). (M. Holmlund, Interviewer)

Nordin, L. (2020). *Life cycle assessments for electric road systems. Review and analysis of LCA studies (VTI PM D. nr 2016/0505-8.1).* Swedish National Road and Transport Research Institute, Infrastructure, Infrastructure maintenance.

Nordin, L., McGarvey, T., & Ghafoori, E. (2020). *VTI rapport 1052A: Electric Road Systems. Impact on Road Construction, Maintenance and Operations.* The Swedish National Road and Transport Institute (VTI).

Port of Gothenburg. (2022, 09 12). *Ports of the world in figures*. Retrieved from https://www.goteborgshamn.se/om-hamnen/varldens-hamnar-i-siffror/?type=11338&area=11339&group=top10&years=1950-2021&chart=table

PowerCircle. (2021). Retrieved from https://press.powercircle.org/posts/pressreleases/nytt-branschoverskridande-projekt-ska-lagga-g

PowerCircle. (2021). Retrieved from (https://powercircle.org/elektrifieradelastbilar.pdf)

Regeringen. (2019). Retrieved from https://www.regeringen.se/495bb6/contentassets/765c6bc603a74a818a726b27e58f1849/reduktionsplikt-for-bensin-och-diesel

Regeringen. (2022, May 05). *Regeringen vill tillåta längre lastbilar på vägarna*. Retrieved from Regeringskansliet: https://www.regeringen.se/pressmeddelanden/2022/05/regeringen-vill-tillata-langre-lastbilar-pa-vagarna/

Regeringskansliet. (2017). Retrieved from Lag (2017:1201) om reduktion av växthusgasutsläpp från vissa fossila drivmedel: https://rkrattsbaser.gov.se/sfst?bet=2017:1201

Regeringskansliet. (2018). *Effektiva, kapacitetsstarka och hållbara godstransporter – en nationell godstransportstrategi.* N2018.21.

Regeringskansliet. (2022). *Regeringskansliet*. Retrieved from Redovisning av kontrollstation för reduktionsplikt tidigareläggs: https://www.regeringen.se/pressmeddelanden/2022/03/redovisning-av-kontrollstation-for-reduktionsplikt-tidigarelaggs/

Rich, J., Kveiborg, O., & Hansen, C. O. (2011). On structural inelasticity of modal substitution in freight transport. *Journal of Transport Geography, 19*(1), 134-146.

RISE. (2021). *Report 2021:23: Digital Systems Electromobility.* RISE.

Swedish Institute for Standards. (2022, 03 01). *About SIS*. Retrieved from https://www.sis.se/en/about_sis/

Taljegard, M., Thorson, L., Odenberger, M., & Johnsson, F. (2020). Large-scale implementation of electric road systems: Associated costs and the impact on CO2 emissions. *International Journal of Sustainable Transportation, 14*(8), 606–619.

TFEU. (2008, 09 05). Consolidated version of the Treaty on the Functioning of the European Union - PART THREE: UNION POLICIES AND INTERNAL ACTIONS - TITLE XVI: TRANS-EUROPEAN NETWORKS - Article 170 (ex Article 154 TEC). *Official Journal 115 , 09/05/2008 P.* Retrieved from https://eur-lex.europa.eu/

The European Parliament and of the Council. (2012, 11 14). *Regulation (EU) No 1025/2012 of the European Parliament and of the Council of 25 October 2012 on European standardisation.* Retrieved from EUR-Lex: http://data.europa.eu/eli/reg/2012/1025/oj

The European Parliament and the Council. (2013). *Council Regulation (EC) No. 1315/2013 of 11 December 2013 on Union guidelines for the development of the trans-European transport network and repealing Decision No 661/2010/EU.* Retrieved from http://eur-lex.europa.eu/

The European Parliament and the Council. (2014, 10 28). Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure Text with EEA relevance. 1–20. Retrieved from http://data.europa.eu/eli/dir/2014/94/oj

The European Parliament and the Council. (2017). Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Directive 1999/62/EC on the charging of heavy goods vehicles for the use of certain infrastructures. *COM/2017/0275 final - 2017/0114 (COD)*. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2017:275:FIN

The European Parliament and the Council. (2019, 03 29). Directive (EU) 2019/520 of the European Parliament and of the Council of 19 March 2019 on the interoperability of electronic road toll systems and facilitating cross-border exchange of information on the failure to pay road fees in the Union (Text with EE. *Document 32019L0520*, 45–76. Retrieved from http://data.europa.eu/eli/dir/2019/520/oj

The European Parliament and the Council. (2019). *DIRECTIVE (EU) 2019/944 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU.* European Union.

The European Parliament and The Council. (2021-01-13). *Directive 2004/52/EC of The European Parliament and The Council of 29 April on the interoperability of electronic road toll systems in the Community.*

Torén, C. (2022, 03 01). Project Manager for electric road technology at Scania. (I. Löfgren, N. Strömdahl, & L. Sundvall, Interviewers) Stockholm: WSP.

Trafikanalys. (2016). *Godstransporter i Sverige - en nulägesanalys.* Rapport 2016:7.

Trafikanalys. (2021). *Yttrande över EU-kommissionens förslag till ändring av direktiv (2014/94/EU) om utbyggnad av infrastrukturen för alternativa bränslen.* Utr 2021/62.

Trafikanalys. (2022). *Godstransporter och konkurrenskraftens utveckling.* Rapport 2022:2.

Trafikanalys. (2022). *Passenger and goods transport 2000-2021.* Statistik 2022:28.

Trafikanalys. (2022). *Swedish national and international road goods transport 2021.* Statistik 2022:16.

Trafikanalys. (2022). *Transporternas energi- och klimateffektivitet.* Rapport 2022:1.

Trafikanalys. (2022). *Vehicle kilometers on Swedish roads.* Statistik 2022:12.

Trafikverket. (2020). *Ajourhandling och identifiering av omledningsvägar (TDOK 2020:0078).* Trafikverket.

Trafikverket. (2020). *Analysmetod och samhällsekonomiska kalkylvärden för transportsektorn: ASEK 7.0.* Borlänge: Trafikverket.

Trafikverket. (2020). *Inriktningsunderlag inför transportinfrastrukturplaneringen för perioden 2022 − 2033 och 2022 − 2037.* Trafkiverket 2020:186.

Trafikverket. (2020). *Klimatstyrmedel i infrastrukturplaneringen – en underlagsrapport till inriktningsunderlaget 2020.* Trafikverket.

Trafikverket. (2020). *Samhällsekonomisk analys för utbyggnad av elvägar respektive laddstationer för tung trafik längs det statliga vägnätet.* TRV 2021:018.

Trafikverket. (2020). *Vägunderhåll och kostnader för olika typer av Elvägar.(TRV 2020/77969).* Trafikverket.

Trafikverket. (2021). *Behov av laddinfrastruktur för snabbladdning av tunga fordon längs större vägar.* Trafikverket.

Trafikverket. (2021). *Förslag till nationell plan för transportinfrastrukturen 2022–2033.* Rapport 2021:186.

Trafikverket. (2021). *Förutsättningar för vätgas som drivmedel för tunga vägtransporter.* Trafikverket.

Trafikverket. (2021). *Regeringsuppdrag - Analysera förutsättningar och planera för en utbyggnad av elvägar.* Trafikverket.

Trafikverket. (2021). *Regeringsuppdrag - Analysera förutsättningar och planera för en utbyggnad av elvägar.* No. TRV 2020/113 361. Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:trafikverket:diva-4498

Trafikverket. (2021). *Remissvar EU-kommissionens förslag till ändring av direktiv(2014/94/EU) om utbyggnad av infrastrukturen för alternativa bränslen.* TRV 2021/87184.

Transportstyrelsen. (2017). *Väg eller järnväg vid transporter av gods – vad säger litteraturen? En förstudie.* Dnr TSJ 2017-3780.

Utfasningsutredningen. (2021). *I en värld som ställer om, Sverige utan fossila drivmedel 2040 (SOU 2021:48).* Stockholm.

VDE Institute. (2021, 12 01). *Organizational Structure*. Retrieved from VDE Institute: https://www.vde.com/en/about-us/organization-chart

Vierth, I., & Björk, L. (2021). *Freight modal shift in Sweden – means or objective?* VTI Working Paper 2021:5.

Vierth, I., Mellin, A., Hylén, B., & Karlsson, R. o. (2012). *Kartläggning av godstransporterna i Sverige: Rapport till Trafikanalys inom uppdraget Transporter av gods – kunskapsunderlag och nulägesanalys.* VTI.

Wietschel, M., Gnann, T., Kühn, A., Plötz, P., Moll, C., & Speth, D. .. (2017). *Machbarkeitsstudie zur Ermittlung der Potentiale des Hybrid-Oberleitungs-Lkw. Studie im Rahmen der wissenschaftlichen Beratung des BMVI zur Mobilitäts-und Kraftstoffstrategie der Bundesregierung.* Fraunhofer ISI, Karlsruhe, Fraunhofer IML, Dortmund, PTV Transport Consult GmbH, Stuttgart, Karlsruhe, TU Hamburg-Harburg, Hamburg, M-Five, Karlsruhe, Germany.

Wråke, M. (2021, 09 07). Ny rapport: Elektrifiering viktigast för att nå klimatmålen. *Ny Teknik*. Retrieved from https://www.nyteknik.se/premium/ny-rapport-elektrifiering-viktigast-for-att-na-klimatmalen-7020325#7019838

Öresundsbron. (2022, 09 12). *Traffic Statistics*. Retrieved from https://www.oresundsbron.com/en/traffic-stats

VI ÄR WSP

WSP är ett av världens ledande analys- och teknikkonsultföretag. Vi verkar på våra lokala marknader med stöd av global expertis. Som tekniska experter och strategiska rådgivare har vi tillgång till ingenjörer, tekniker, naturvetare, planerare, utredare och miljöspecialister liksom professionella projektörer, konstruktörer och projektledare. Vi erbjuder hållbara lösningar inom Hus & Industri, Transport & Infrastruktur och Miljö & Energi. Med ungefär 70 000 medarbetare på 500 kontor i 40 länder medverkar vi till en hållbar samhällsutveckling. I Sverige har vi omkring 4 000 medarbetare.

WSP Sverige AB

121 88 Stockholm-Globen
Besök: Arenavägen 7

T: +46 10 7225000
Org nr: 556057-4880
Styrelsens säte: Stockholm
wsp.com