Swedish-German research collaboration on Electric Road Systems

Connecting Countries by Electric Roads

Methodology for Feasibility Analysis of a Transnational ERS Corridor

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Content

Executive Summary

The present study aims at discussing relevant aspects for a potential roll-out of Electric Road Systems (ERS) on transnational corridors, as well as generally for ERS introduction in Europe.

Feasibility criteria have thus been developed in order to assess the following topics for specific potential ERS corridor projects:

- Technical aspects: Which technical prerequisites exist for ERS corridors and to which extent can they expected to be met?
- Environmental aspects: Which effects can be expected on key environmental indicators?
- Economic aspects: Can an ERS corridor pose a business case? Could it contribute to the improvement of ERS economy in general?
- Political aspects: Would an ERS corridor implementation make sense from a political point of view?

The developed criteria may serve as a toolbox for scrutinizing future transnational ERS corridor projects. In order to illustrate their application, we used them to analyse a potential roll-out of an Electric Road System on a selected highway corridor (424 km) connecting **Sweden** and **Germany**, but mainly located on Danish territory. Based on traffic flows and patterns along the corridor route, it was found:

- A considerable part of the total truck mileage on the corridor is done by vehicles with a rather limited driving distance for pre- and post-haul, assuming the corridor is realized as a stand-alone project, and
- the CO_2 emissions (well-to-wheel) of truck traffic along the corridor route can be significantly reduced if electric trucks are powered by the national electricity mixes expected for the year 2030, and even more if it would be powered purely renewable.

Although a continuous ERS on the complete corridor route would not be economically feasible under current conditions, the analysis pinpoints sections along the route where the traffic volumes with a sufficient share of operation on a potential ERS are significantly higher. These sections are located in the metropolitan areas of Malmö, Copenhagen and Hamburg. For implementation, peculiarities of the local markets and regulation should be considered, as well as country-specific priorities on decarbonizing road freight transport. Additionally, the identified ERS potential for medium distances will depend on the technical and cost development of battery trucks.

Our analysis also sheds some light on the **role of first transnational corridors within a European roll-out strategy for ERS**. Such corridor projects could help to

- proof the principal strengths of ERS,
- trigger strategic coordination between the participating countries,
- foster national ERS roll-out due to synergy effects with the corridor and
- pave the way for integration of ERS into EU legislation (e.g. AFID, TEN-T planning)

List of Abbreviations

ADT	Average daily traffic
DE	Germany
DK	Denmark
ERS	Electric Road System
ERS-BEV	Battery Vehicle able to connect to ERS
ERS-HEV	Hybrid Vehicle able to connect to ERS
FI	Finland
GHG	Greenhouse Gases
HGV	Heavy Goods Vehicle
ICEV	Internal Combustion Engine Vehicle
NO	Norway
OD	Origin-Destination
SE	Sweden
SGEC	Swedish-German ERS corridor
TCO	Total Cost of Ownership
VAT	Value Added Tax

1 Scope

In recent years, the urgent need for action in climate policy has become increasingly apparent. The focus has shifted in particular to freight transport, whose greenhouse gas (GHG) emissions continue to rise due to rising transport volumes; from 1990 until 2018, transport-related GHG emissions in EU-28[1] have increased by 20 % from 794 million tonnes to 950 million tonnes CO_2 equivalents per year [1]. Electric Road Systems (ERS) are therefore attracting growing attention as a climate protection technology, especially for long-haul heavy freight transport which faces severe hurdles for electrification via battery vehicles.

In Sweden and Germany, there have been various research and development activities relating to ERS in recent years. Since 2017, there is a declaration of intent between the two countries regarding joint ERS research and innovation [2].

Previous research has mainly focused on a better understanding of the individual aspects of ERS (technical system, standardisation, cost estimates, etc.). Now the first field trials are in operation and at least in Sweden a roadmap for implementation has been developed [3]. At the same time, the importance of a transnational approach to ERS is often stressed, as many transports are international and generally, there is a strong integration in the European market.

This study has developed feasibility criteria mainly based on transport flows and vehicle usage patterns along an international freight corridor, and thereby getting an understanding for the potential of electrification of heavy-duty road freight.

Technical, economic, environmental, but also political-strategic aspects will play a role in an assessment of the usefulness of establishing an ERS transport corridor.

The aim is to highlight the challenges of a transnational ERS and to discuss implementation strategies by the involvement of relevant stakeholders of the countries that are concerned.

In order to illustrate the developed criteria, we apply certain aspects to a Swedish-German corridor route. However, this study is not meant as a comprehensive feasibility analysis, but rather as a methodological contribution to research on a possible international ERS roll-out.

This report first explains the developed feasibility criteria (Section 2). Subsequently, the results of their exemplary application to corridor route between Scandinavia and Germany are summarized (Section 3). Based on these results, we finally draw some conclusions and give recommendations for future assessment of transnational ERS projects (Section 4). This also includes the question of what role such a corridor could play in the introduction of ERS in Europe. For details of the exemplary corridor assessment, the reader may refer to an extensive annex.

Readers in need of a state-of-the-art description of ERS, should refer to the CollERS report “Overview of ERS concepts and complementary technologies” [4]

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[1] The 27 present EU Member States and the United Kingdom.

2 Feasibility criteria for a case study

The present study aims at discussing all aspects that could be relevant for analysing the feasibility of a transnational ERS corridor, as well as for a study of ERS introduction in Europe. Relevant aspects can be classified into four groups:

- Technical aspects: Which technical prerequisites exist for the ERS corridor and to which extent can they expected to be met?
- Environmental aspects: Which effects can be expected on key environmental indicators?
- Economic aspects: Can an ERS corridor pose a business case? Could it contribute to the improvement of ERS economy in general?
- Political aspects: Would an ERS corridor implementation make sense from a political point of view?

In the following scheme, we explain the individual parameters in each category which are the basis for the assessment.

#	Parameter	What goes into it?	Why is it important?
1	**Technical**		
1.1	Electric mileage	Traffic flow analysis, technically possible electric pre- and post-haul distances for the chosen ERS vehicles	An ERS only makes sense if it enables vehicles to operate on electricity, thus saving fossil fuel. This parameter is also an input for other criteria such as GHG emission reduction and improvement of air quality.
1.2	Availability of electricity supply	Electricity demand and production in the affected regions, capacity of distribution grid, renewable energy targets	In order to reach massive GHG emission reductions, a high share of renewables in the electricity mix for ERS is crucial. Moreover, expansion of electricity grids for ERS can yield high costs.
1.3	Interoperability	Definitions of common interfaces, maturity and availability of standards	Differing technical (and possibly administrative) standards between the participating countries can significantly increase necessary efforts for a cross-border ERS.

#	Parameter	What goes into it?	Why is it important?
2	**Environmental**		
2.1	Reduction of climate gas emissions	Suitable traffic volumes, energy consumption, emission factors	The need for decarbonisation of road freight traffic constitutes the primary political driver for the introduction of ERS.
2.2	Improvement of air quality	Suitable traffic volumes, emission classes of affected traffic, air quality figures along the corridor	NOx limit values are currently exceeded in many densely populated areas in the EU. If ERS can alleviate this situation, this could be a major driver for system introduction.
2.3	Reduction of noise emissions	Acoustic measurements from other projects, expected vehicle speed, population density along the corridor	Noise from road traffic has several negative effects (i.e. health issues, depreciation of real estate), especially in urban areas. Introduction of electric drive systems can in principle reduce noise emissions.
3	**Economic**		
3.1	TCO advantage of operators	Vehicle prices and expected development, share of operation on ERS corridor, energy prices	An ERS corridor will only be widely used if operation of ERS vehicles leads to a cost reduction for haulage-companies or at least does not imply a financial disadvantage.
3.2	Expected investment and infrastructure operating costs (compared to other public investments in the same or neighbouring sectors)	Cost estimations from ongoing studies and field tests, extrapolation due to scale-up	Building an ERS corridor will require significant investments for which the payback time is difficult to foresee. Most stakeholders seek to reach climate goals with minimum input of financial resources. Low GHG abatement costs thus increase the likelihood of ERS realization.
3.3	Contribution to creating a substantial vehicle market	Tipping points of vehicle numbers as communicated by manufacturers	Economies of scale can help to drive down the price for ERS technology, which can in turn increase its market penetration. Thus, growing the ERS vehicle market may be an argument for an ERS corridor implementation in an early market phase.
3.4	Committing logistical and industrial stakeholders (carriers, shippers, vehicle manufacturers)	Stakeholder interviews	Successful ERS introduction needs a simultaneous commitment of different stakeholder groups. If an ERS corridor can foster such commitment, that could be an argument for its realization.

#	Parameter	What goes into it?	Why is it important?
4	**Political**		
4.1	Contribution to (technical and political) cross-border strategy for large scale implementation	Stakeholder interviews	Implementation of a transnational ERS corridor in an early phase of ERS introduction is not likely to take place solely driven by market mechanisms. It requires significant political effort. Consequently, there need to be considerable advantages of such a project also on a political level. These are investigated here.
4.2	Bridging the gap between demonstration and infrastructure scale-up	Stakeholder interviews	
4.3	Ensuring credibility of decarbonization efforts	Stakeholder interviews	
4.4	Lighthouse effect for ERS: raise stakeholder awareness, increase confidence in the ERS-technology and its feasibility	Stakeholder interviews	

3 Summary of assessment

The criteria presented in the previous section may serve as a toolbox for scrutinizing future transnational ERS corridor projects. In order to illustrate their application, we used them to analyse a potential roll-out of an Electric Road System on a selected highway corridor (424 km) connecting Sweden and Germany, but mainly located on Danish territory. The following scheme summarizes key results from each assessment criterion that was applied in the analysis.

#	Parameter	Main findings	Conclusions for feasibility
1	**Technical**		
1.1	Electric mileage	• 45 % of total HGV mileage on the corridor have a pre- and post-haul less than 250 km. • The above HGV have routes with 22 % mileage on the corridor	+ considerable share of routes on the corridor, and part of these could be suitable for ERS. - rather low relative mileage on the corridor
1.2	Availability of electricity supply	• The high voltage grid has already been reinforced due to high RE generation along the corridor route • Power demand from the corridor could in some cases alleviate peak RE feed-in situations	+ It seems unlikely that the high voltage grid needs to be reinforced considerably for ERS. Dedicated medium voltage grids need to be installed to connect the ERS to the HV grid
1.3	Interoperability	• Multiple dimensions of interoperability may play a role for the corridor (international, inter- and intra-system) • Standardization regarding certain ERS components is on the way at European level (CENELEC)	- There are yet no standardized solutions ready for application.

#	Parameter	Main findings	Conclusions for feasibility
2	**Environmental**		
2.1	Reduction of climate gas emissions	• CO2 reduction for total HDV traffic on the corridor is estimated at 33 % if all suitable trips would be done by hybrid ERS vehicles. • Presence of national ERS networks could increase CO2 savings to about 50 %	+ ERS corridor enables deep CO_2 reductions per vehicle due to favourable electricity production in the Scandinavian countries.
2.2	Improvement of air quality	• In Hamburg, Copenhagen and Malmö, there are considerable challenges regarding NOx in the air. • Only a small fraction of NOx originates from vehicles on the corridor route	- Air quality impact of electric drive on the corridor is expected to be rather low in the affected urban regions. + If ERS vehicles would operate purely electric also in pre- and post-haul, positive effects on air quality could be considerably higher.
2.3	Reduction of noise emissions	• Reduction in noise emissions due to electric drive are only relevant for low speeds of up to 30 km/h. • There are most likely differences in noise emissions between ERS technologies.	- Noise reduction by ERS in free-flowing motorway situations cannot be expected. + ERS vehicles can lower noise emissions in congested areas and in urban pre- and post-haul if this is done in electric mode.

#	Parameter	Main findings	Conclusions for feasibility
3	**Economic**		
3.1	TCO advantage of operators	• With current ERS vehicle prices, a significant TCO advantage cannot be expected for any of the considered countries. • If a market for ERS vehicles is established and scale effects can be taken advantage of, a TCO advantage will probably emerge. • The German HDV road toll is an effective means for supporting market entry of ERS vehicles.	- In the beginning, ERS vehicles are likely to need fiscal support measures. + With market scale-up, an economic operation is likely, particularly in Sweden with its comparably low electricity price.
3.2	Expected investment and infrastructure operating cost	• Electrification of the whole ERS corridor will yield annual overall system costs of about 100 M€ • By selecting most suitable sections of the corridor, the cost balance can be significantly improved, yielding CO_2 abatements costs of well below 200 €/tonne CO_2.	Electrification of the whole corridor is not likely to pay off under the current regulatory framework. However, electrifying only suitable parts of the corridor can pose a competitive CO_2 mitigation option.
3.3	Contribution to creating a substantial vehicle market	• The ERS-suitable traffic flows on the corridor correspond to around 12 000 ERS vehicles	+ OEMs would likely scale their production processes to mass-market in this case
3.4	Committing logistical stakeholders and industrial stakeholders	• Decisions of haulage companies depend mostly on economic aspects; ERS vehicles have to pay off • Intermodal transport often has advantages in terms of operational aspects (repose period for drivers)	Intermodal transport will continue to play a role even with the Fehmarn Belt Fixed Link. Future autonomous trucks would make a Swedish-German ERS corridor much more attractive

#	Parameter	Main findings	Conclusions for feasibility
4	**Political**		
4.1	Contribution to cross-border strategy for large scale implementation	• A corridor requires trans-national standardization • Considerable dependencies with national ERS roll-out can be expected	A corridor project could + trigger strategic coordination between the participating countries + foster national ERS roll-out due to synergy effects + raise awareness for ERS at EU level (regulation like AFID, TEN-T planning, …)
4.2	Bridging the gap between demonstration and infrastructure scale-up	• Corridor project could be an intermediate step between introduction phase and large-scale implementation	+ There are several potential public funds for a trans-national corridor project. - Implementation would be significantly easier when national ERS networks are already (partly) present.
4.3	Ensuring credibility of decarbonization efforts	• International coordination is often mentioned as vital for successful ERS roll-out • A trans-national ERS corridor bears notable political challenges	+ Successful implementation of a trans-national ERS corridor would probably be perceived as a strong political statement regarding importance of ERS technology.
4.4	Lighthouse effect for ERS	• ERS corridor would expose a large number of people to ERS technology • Attraction of considerable media attention is likely	+ considerable impact as a showcase project is likely

4 Conclusions and recommendations

Electrifying the 424 km long traffic corridor between Hamburg and Helsingborg with ERS technology will require an exceptional effort from a variety of stakeholders and industrial sectors. At the same time there is potential to decarbonize heavy-duty transportation across national borders for the German-Scandinavian region. Traffic data shows that a high number (45 %) of current heavy-duty traffic on the corridor have trips with pre- and post-haul distances of less than 250 km, based on the start and stop destinations of transportation routes in this region. Simultaneously, the data also shows that there are some adjoining routes to the corridor with substantial traffic flows, for example north of Helsingborg, road E47 westward in Denmark, and south of Hamburg that could act as national ERS-networks which would amplify the desired effects and outcomes of ERS implementation in the EU.

In the course of the project, it has been determined that the optimal way to provide the ERS-corridor with electricity should be through a connection to the high voltage level of the electric grid, with a medium voltage wayside grid that runs parallel to the road. Initial assessments indicate that such connections can be made without further investment in the capacity of the high voltage grid, nor additional electricity generation facilities for the entire extension of the corridor through all three countries.

Assuming this design, preliminary estimates put the total investment cost of ERS infrastructure (including technology-specific- and auxiliary road infrastructure) to about 1 billion $€_{2019}$ for the entire ERS corridor. Furthermore, additional costs to manufacture trucks capable of connecting to the ERS will play an important role particularly in the first phase of system introduction and will need to be at least partly covered by appropriate public grants. It is estimated that the construction of an ERS corridor in the considered scale is likely to also spur a large-scale production of ERS-trucks, which will bring down vehicle costs and will likely facilitate the general implementation and scaling-up of ERS technology, both within and outside this current case study. Current economic models predict a net-positive economic effect of ERS once a substantial ERS-network is present (about 2000 kilometres). As the corridor is only 424 kilometres long, it should be viewed as a steppingstone toward a long-term international ERS network roll-out that is likely to be more profitable than an isolated corridor. An important factor will also be to coordinate the construction of international ERS deployments with national ERS activities, i.e. sync the construction of international corridors with the national ERS roadmaps and construction plans for the bordering countries.

Whether the ERS corridor will become a viable economic business or not, will eventually depend on the adoption of the technology within the logistics sector and the future development of competing technologies offering fossil-free operation such as pure battery trucks for long-haul applications or fuel cell trucks. In turn, ERS technology adoption and achievable economic advantages for operators will largely depend on a stringent public climate policy (e.g. in terms of CO2 price) and on a predictable infrastructure roll-out which requires a corresponding commitment on the part of responsible public authorities. In general, hauliers are currently positive about alternative drive technologies and mindful of their carbon footprint. However, this would not be reason enough to electrify their vehicle fleet since the logistics sector is characterized by intense competition. Thus, a crucial aspect in catalysing the logistics sector to adopt ERS technology would be to set up a system where, through ERS, they reach a lower (or at least not higher) total cost for vehicle ownership and operation compared to what the current system, or other fossil-free systems such as battery electric or fuel cell power systems, can offer for a particular application.

The utilization of an ERS corridor will depend on the future development of HDV traffic patterns, particularly the relevancy of intermodal transportation flows. If railway infrastructure can be successfully expanded, leading to a large-scale shift of long-haul road-freight transport to railways, ERS could be a feasible option particularly for feeder traffic in intermodal transports. This should be considered for infrastructure planning. On the other hand, autonomous driving for trucks could potentially raise attractiveness of long-haul road transports compared to intermodal transports using ferry links which currently act as resting opportunities for truck drivers.

If all the traffic with pre- and post-haul trips of less than 250 km were electrified through ERS using hybrid vehicles that will run on electricity while on the ERS, around a third of all CO_2 emitted from heavy transportation on the analysed corridor could be mitigated. The amount of mitigated CO_2 on the corridor is dependent on the source of electricity in the country which the corridor passes, making electric drive favourable in this region based on a high current share of renewables in the electricity mix in the Scandinavian countries, which is also projected to increase in all three countries in coming years.

Even though there are issues with air quality in all three major cities along the corridor (Malmö, Copenhagen and Hamburg), the HDV traffic on the corridor is only contributing to this in a marginal way. Thus, installing an ERS would not automatically imply a substantial improvement of urban air quality along the corridor. However, if the vehicles are designed to also use their electric drive outside the ERS corridor (e.g. if they are equipped with a larger battery), a considerable positive effect on air quality would be possible.

Although substituting an internal combustion engine with an electric motor comes with an expected lowering of noise generated by the vehicle, this effect is only significant when the vehicle is driving 30 km/h or less. Thus, introducing an ERS would only positively affect noise levels in urban low-speed environments or congested areas, which does not align with the characteristics of the proposed ERS-corridor as it is meant to be built on highways. As for air quality, a significant decrease in noise emissions might be due to electric drive of ERS vehicles in pre- and post-haul in urban areas.

Realizing an ERS of this magnitude would require transnational political support, standardization efforts and strategic coordination between not only the governing bodies of the countries involved but also a number of stakeholders from key industries (vehicle manufacturing, electrical utility, hauliers etc.). Such efforts have started to take form to a certain degree on an EU level, for example standardisation efforts of ERS technology through CENELEC. It will probably prove a considerable challenge to successfully scale-up ERS technology out of the current testing phase in many different regards (technical, legal, economical etc.). On the other hand, it would signal a serious effort to electrify the transportation sector from both the public and private sector and may serve as an important example for others to follow in regard to ever more stringent climate goals and urgency for sustainable societies.

An international cooperation of this scale would also probably spur the construction of national and more localized ERS-networks, not only in the three countries affected in the current corridor case study but also other countries within the EU as well as globally. There is also merit to the notion that construction of the analysed ERS corridor would require (or at least greatly benefit from) a parallel construction of national ERS-networks in the affected countries. A project of this size would most probably also expose a lot of people to ERS technology in particular, but also electrification/decarbonization efforts in general and may thus act as both a public and professional catalyst in future sustainability efforts.

The findings in this case study so far point toward implementing a rollout strategy for the ERS corridor in a series of stages as opposed to electrifying the entire corridor in one go. The proposed rollout strategy will initially focus on the ends of the corridor (Hamburg-Lübeck and Helsingborg-Malmö), which are characterized by shorter stretches that are heavily trafficked and could simultaneously serve as the foundation for the construction of national ERS-networks in both Sweden and Germany. Next, the section through Denmark (particularly the northern part between Copenhagen and Køge) should be considered for electrification. This section is comparably long, characterized by high traffic flows and will thus play a crucial part in mitigating large amounts of CO_2. The remaining section between Lübeck and Rödby is currently characterized by the lowest traffic flows on the corridor; however, this might change with the introduction of new road infrastructure (Fehmarn Belt Fixed Link).

The roll-out strategy described above assumes that also regional transports with total distances of less than 200 km would potentially benefit from an ERS. However, for such trips, we can expect that pure battery electric trucks will become more suitable also for medium distances if battery costs would continue to decrease. Generally speaking, there will be a trade-off between costs for the vehicle-side ERS components, costs for additional battery capacity, and the cost of using ERS compared with the cost of using stationary charging. Future research needs to further investigate under which conditions regional and long-distance freight traffic could benefit from lower operating costs by using an existing ERS. This could significantly influence roll-out strategies for ERS.

This study about a potential Scandinavian-German ERS corridor yielded a number of results which can be used as input for general studies of international ERS corridors in Europe. This is true especially for the general requirements for implementation as well as for the role an international ERS corridor may play within a larger implementation of ERS in Europe. The criteria set developed in this study may be used to assess further potential international ERS corridor routes, but need further development to accurately estimate the potential. It could serve as a basis for the development of a toolkit designed to explore European implementation pathways for ERS.

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6 Annex

6.1 Freight transport between Scandinavia and Germany

6.1.1 Status quo of transports

A feasibility analysis of a potential Swedish-German ERS corridor will be focused on landside road freight transport. Nevertheless, rail transports are included in the following description of transport flows in the study area between Sweden and Germany because there is a possible competition situation between railway and road traffic. Freight traffic with trucks via the different ferry lines across the Baltic Sea, the Kattegat and the Skagerrak plays an important role for goods transports between Germany and the Scandinavian countries – these traffics are counted to road freight transport, because the main mode for transporting the goods from origin to destination is the truck transportation, the ferries are only used to a shorter or longer distance in between. Pure maritime freight transports are not listed because they are not relevant for ERS, but feeder traffic to and from the ports with landside transport modes is included in the description. One important data source for transport and traffic flows in the CollERS study area is the Fehmarn Belt Forecast 2014 [5], more and detailed information about data sources, data collection and data processing can be found there.

6.1.1.1 Transport flows

Table 1 shows the transport flows between the Scandinavian countries and Germany per mode for 2011. Transport flows to and from Denmark are separated into Denmark West and Denmark East. The first ones are of minor importance for an ERS corridor because they follow the road and motorway network from Hamburg northwards to the Danish border in Jutland and might strike the possible ERS-corridor[2] only on short stretches between Hamburg and Lübeck.

Within the study area, road transport has a market share of nearly 80 % in total, including Denmark West it is 82 %, even higher for transports with Denmark, Norway and Finland, but lower for transports to and from Sweden (about 73 %). Neglecting the transport flows to Western Denmark, Sweden is the most important country in Scandinavia concerning transport flows with Germany.

Table 1: Origin-destination transport flows between Scandinavian countries and Germany (including transit traffic via Germany) per mode in 2011. Data Source: Fehmarn Belt Forecast 2014

Country	Rail 2011 (1000 tonne/year)	Road 2011 (1000 tonne/year)	Modal Share of Rail	Modal Share of Road
Denmark	2 555	20 035	11 %	89 %
- Denmark West	2 257	16 445	12 %	88 %
- Denmark East	298	3 590	8 %	92 %
Norway	125	2 617	5 %	95 %
Sweden	5 730	15 500	27 %	73 %
Finland	10	904	1 %	99 %
Total (without Denmark West)	**6 163**	**22 611**	21 %	79 %

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[2] See Sec. 6.2.1.

As shown in Table 2, most of the transported goods between Scandinavia and Germany are related to “miscellaneous articles”, followed by “other manufactured articles” and “metals”. “Miscellaneous articles” are transported in containers to a large extent, therefore the high share of combined rail/road transports. On rail only selected commodity groups are transported, but all commodity groups are transported by road as well – the modal share of road transport is over 50 % for all commodity groups.

Table 2: Traffic volume between Scandinavia and Continental Europe by commodity groups and transport modes in 2011 (without Denmark West). Data Source: Fehmarn Belt Forecast 2014

Commodity group	**Road 2011**		**Rail conventional 2011**		**Rail combined 2011**		**Total 2011**
	Volume (1000 tonne/year)	**Modal Share**	**Volume (1000 tonne/year)**	**Modal Share**	**Volume (1000 tonne/year)**	**Modal Share**	**Volume (1000 tonne/year)**
Agriculture, hunting and forestry	2 499	100 %	8	0 %	0	0 %	2 507
Food products, beverages and tobacco	2 531	98 %	53	2 %	0	0 %	2 584
Wood and cork, pulp, paper	3 026	75 %	1 034	25 %	0	0 %	4 060
Coal, petroleum, natural gas, coke	118	99 %	1	1 %	0	0 %	119
Ores, mining and mineral products	1 204	90 %	135	10 %	0	0 %	1 339
Metals	2 264	59 %	1 581	41 %	0	0 %	3 845
Chemicals, chemical products	1 525	85 %	264	15 %	0	0 %	1 789
Transport equipment and machinery	2 471	97 %	89	3 %	0	0 %	2 560
Other manufactured articles	3 947	96 %	159	4 %	0	0 %	4 106
Miscellaneous articles	3 025	52 %	608	10 %	2 233	38 %	5 866
Sum	**22 611**	**79 %**	**3 931**	**14 %**	**2 233**	**8 %**	**28 775**

Transport flows between Scandinavia and Continental Europe are almost symmetric: in 2011 goods transported from Scandinavia to Continental Europe amounted to 14 127 tonnes, whereas from Continental Europe to Scandinavia 14 647 tonnes were transported.

6.1.1.2 Road freight traffic flows

Development of road freight traffic flows between Continental Europe and Scandinavian countries since 1995 is demonstrated in the following figures using average trucks per year as a unit. They all show that total road traffic flows in the study area have more than doubled on the displayed sections between 1995 and

2018, which means average annual growth rates of more than 3 % per year[3], interrupted by declines due to the worldwide economic crisis beginning in 2008. Meanwhile, the level of traffic flows has reached the levels before the crisis, between Denmark and Sweden the level is now even higher than ever before. In Denmark and Sweden, ferry links lost market shares after opening of Great Belt Bridge in 1998 and Øresund Bridge in 2000, both bridges did not only gain traffic flows from ferries but also led to further economic integration of the linked regions and therefore to increasing traffic flows.

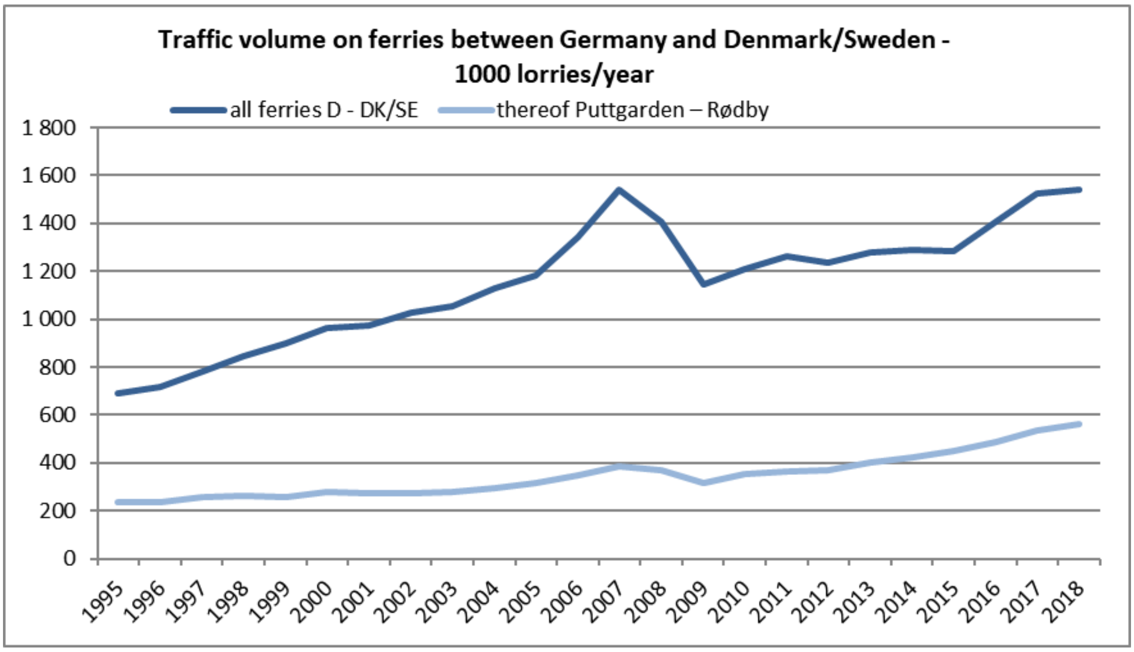

Figure 1: Development of traffic volumes on ferries between Germany and Denmark/Sweden from 1995 to 2018 - in 1.000 lorries per year. Data sources: Danmarks Statistik (statbank.dk), Trafikanalys (trafa.se)

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[3] Average annual growth rate for trucks from 1995 to 2018 is at 3.6 % in sum of all ferries between Germany and Denmark/Sweden, at 3.3 % in sum of ferries in Denmark and Great Belt Bridge and at 3.8 % in sum of ferries between Denmark and Sweden and on Øresund Bridge.

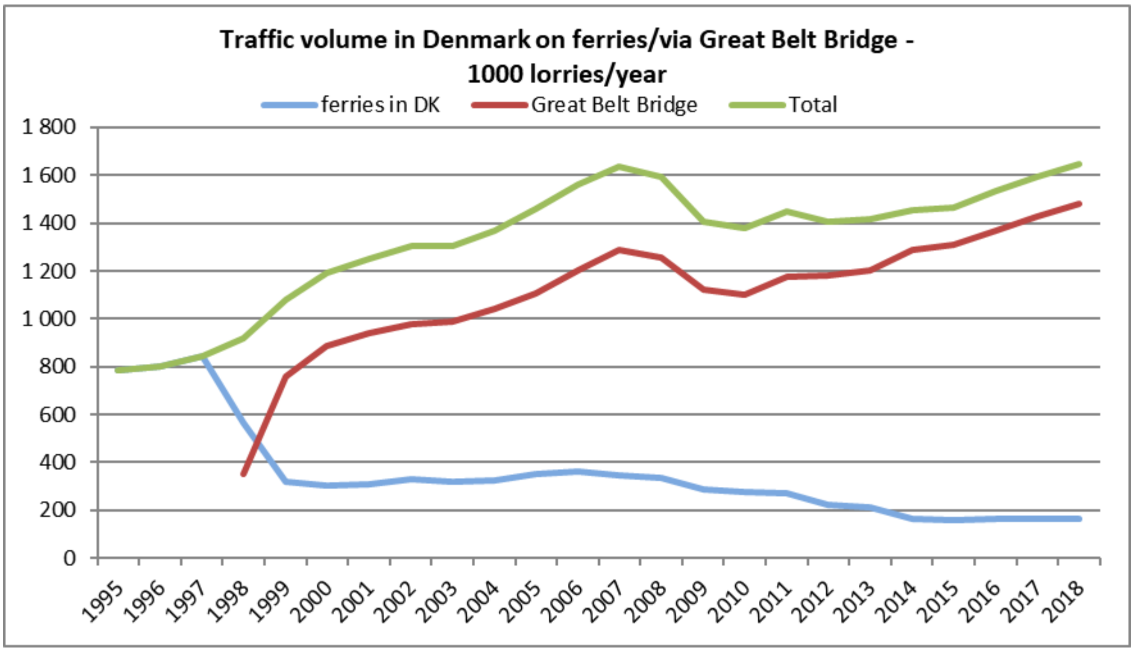

Figure 2: Development of traffic volumes in Denmark from 1995 to 2018 – in 1 000 trucks per year. Data sources: Danmarks Statistik (statbank.dk), Storebaelt.dk

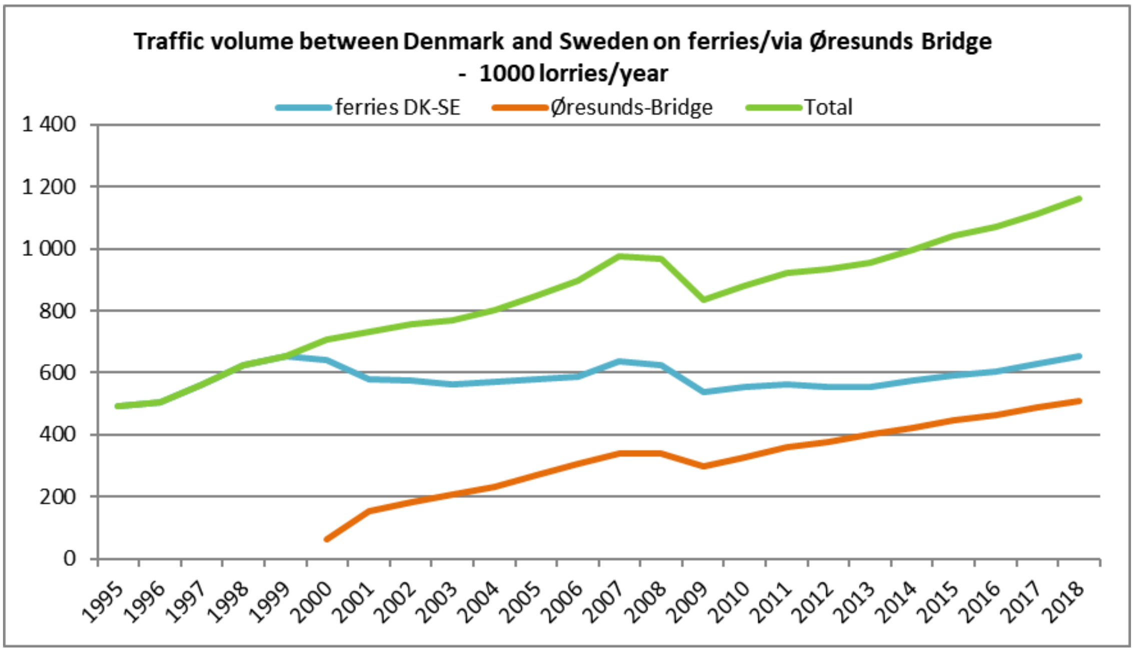

Figure 3: Development of traffic volumes between Denmark and Sweden from 1995 to 2018 – in 1 000 trucks per year. Data sources: Danmarks Statistik (statbank.dk), Oresundsbron.com

6.1.2 Expected developments

Future development of freight transport flows in the study area depends to a large extent on the development of trade volumes – of domestic trade volumes in the countries of Germany, Denmark and Sweden on the one hand and of foreign trade volumes between the Scandinavian countries and the European continent on the other hand. Development of foreign trade volumes until 2030 under consideration of expansion of road and rail infrastructure[4] in the study area could be adopted from the Fehmarn Belt Forecast of 2014 [5], see the following three tables describing the development of freight transport volumes in thousand tonnes per year and per country (Table 3), per mode (Table 4) and per commodity group (Table 5).

Table 3: Forecasted transport flows between Scandinavian countries and Germany (including transit traffic via Germany) per country from 2011 to 2030. Data Source: Fehmarn Belt Forecast 2014

Country	2011		2030 (Case B)		Yearly Growth 2011–2030
	Volume (1000 tonne/year)	Share	Volume (1000 tonne/year)	Share	
Denmark East	3 888	14 %	5 834	13 %	2.2 %
Norway	2 742	10 %	4 111	9 %	2.2 %
Sweden	21 230	74 %	34 435	75 %	2.6 %
Finland	913	3 %	1 386	3 %	2.2 %
Sum	**28 774**	**100 %**	**45 766**	**100 %**	**2.5 %**

Table 4: Forecasted road and rail transport flows between Scandinavian countries and Germany (including transit traffic via Germany) from 2011 to 2030. Data Source: Fehmarn Belt Forecast 2014

Mode		2011	2030 (Case B)	Yearly Growth 2011–2030
road	1000 tonne/year	22 611	35 651	2.4%
	tonne share	78.6%	77.9%	0.0%
rail	1000 tonne/year	6 164	10 116	2.6%
	tonne share	21.4%	22.1%	0.2%
total	**1000 tonne/year**	**28 774**	**45 766**	**2.5%**
	tonne share	**100.0%**	**100.0%**	**0.0%**

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[4] Fehmarn Belt Fixed Link with road- and rail-infrastructure replaces ferry link Puttgarden – Rødby, completed motorway network in Germany with A 39 Lüneburg – Wolfsburg, A 14 Schwerin – Magdeburg and A 20 northern bypass of Hamburg with Elbe-crossing amongst others.

Table 5: Forecasted transport flows between Scandinavian countries and Germany (including transit traffic via Germany) per commodity group from 2011 to 2030. Data Source: Fehmarn Belt Forecast 2014

Commodity group	2011 (1000 tonne/year)	2030 (Case B) (1000 tonne/year)	Yearly Growth 2011–2030
Agriculture, hunting and forestry	2 507	3 861	2.3 %
Food products, beverages and tobacco	2 585	399	2.3 %
Wood and cork, pulp, paper	406	6 348	2.4 %
Coal, petroleum, natural gas, coke	119	118	0.0 %
Ores, mining and mineral products	1 338	1 576	0.9 %
Metals	3 844	5 737	2.1 %
Chemicals, chemical products	1 789	3 239	3.2 %
Transport equipment and machinery	256	4 393	2.9 %
Other manufactured articles	4 106	6 658	2.6 %
Miscellaneous articles	5 866	9 848	2.8 %
Sum	**28 774**	**45 766**	**2.5 %**

In total transport flows between the Scandinavian countries and Continental Europe are expected to grow by 2.5 % per year between 2011 and 2030, for road freight transport a little bit lower with 2.4 % per year and for rail traffic a little bit more with 2.6 % per year. Modal share of rail transports will increase slightly from 21.4 % in 2011 to 22.1 % in 2030.

Although ferry line Puttgarden – Rødby is assumed to be replaced by the Fehmarn Belt Fixed Link, transport routes between Sweden and Germany via alternative ferry links still will play an important role then.

Not all relevant transport flows for the present CollERS study are covered by the Fehmarn Belt Forecast of 2014, the traffic forecast for 2030 [6], and the forecast 2050 for the German StratON-project [7], so development of the remaining flows had to be forecasted on basis of other sources and information. Table 6 contains an overview per origin-destination (OD) pair on level of countries about the used data sources for the forecasts of the freight traffic flows for 2030 and 2050 and on the expected growth of traffic volumes from 2011 to 2030 and 2050. Section 6.2.2 contains further details on the traffic flows particularly on the chosen corridor route.

Table 6: Assumed development of transport flows per origin-destination (OD) until 2030 and 2050 - growth in % compared to 2010 (=100) and used data sources

OD-pair	2011	2030	2050	Base/Data-Source
DE – Scandinavia	100	157	197	Fehmarn Belt Forecast 2014 / Traffic Forecast 2030 / StratON 2050
DK – DK	100	135	171	No official forecasts for Denmark available, growth rates derived from development until
DK – NO, FI	100	143	196	

DK – SE	100	155	239	2018 and comparison with development in neighbouring countries
SE – SE	100	136	179	Swedish Transport Administration forecast for freight transport 2040 [8]
SE – NO, FI	100	143	196	Derived from Swedish Transport Administration forecast for freight transport 2040

In general, there are two trends visible:

- growth rates in the future are expected to be lower than the observed ones in the past[5] which have been over 3 % per year – between 2011 and 2030 freight traffic between Germany and the Scandinavian countries has the highest forecasted annual growth rate with 2.4 %, from 2011 to 2050 its between Denmark and Sweden with 2.3 %, and
- international freight traffic flows are expected to increase stronger than domestic flows due to stronger growth of foreign trade.

Femern A/S, responsible for construction and operation of the Fehmarn Belt Fixed Link, expects opening of the link from today's point of view in 2028[6]. It will then offer purely landbound and direct connections on road and rail between Hamburg and Copenhagen/Malmö. Especially rail freight traffic between Germany and Scandinavia is expected to shift to a large extent to this new link which will be considerably shorter than the alternative route via the Great Belt. For road freight traffic the new link will also offer improved connections, but not in that extent as in rail traffic and therefore share of transports via the route over Puttgarden – Rødby will increase only slightly.

Limitation of traffic flows due to missing capacities in infrastructure, rail and road, play a minor role on most parts of the corridor today and in the future, but of course traffic flows (in freight and in passenger traffic) are more dense in the metropolitan regions of Hamburg, Copenhagen and Malmö, congestions are delays are more frequent there.

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[5] This is due to more conservative assumptions regarding growth of GDP.

[6] https://femern.com/en/Tunnel/Project-status/Milestones-for-the-project

6.2 Description of Exemplary Corridor Route

6.2.1 Selection of corridor route

Looking at traffic flows between Continental Europe resp. Germany and Scandinavia, three main transport corridors for land-bound traffic can be identified:

a) from Hamburg via Flensburg and the Great Belt crossing the Öresund;
b) from Hamburg via Lübeck, crossing the Fehmarn Belt between Puttgarden and Rødby and over the Öresund; and
c) from Hamburg/Berlin to Rostock, via the Baltic sea to Gedser and crossing the Öresund;

in combination with several ferry lines which offer alternative transport routes crossing the Baltic sea like Lübeck – Malmö/Trelleborg, Rostock – Trelleborg, Kiel – Gothenburg, Helsingør – Helsingborg and more.

Route b) via the Fehmarn Belt using the ferry link is already very important today and it will become even more important in the future after realisation of the Fehmarn Belt Fixed Link. Then it will offer a purely landbound and direct motorway and railway connection between the metropolitan areas of Hamburg, Copenhagen, Malmö, Gothenburg and Stockholm and thus it will be the most meaningful corridor for a possible ERS-connection between Sweden and Germany[7].

The potential ERS-corridor examined in detail in this study is shown in Figure 4. It starts at Helsingborg in Sweden following the route E6 south to Malmö, crossing the Öresund via the fixed link to Copenhagen and following the route E47 via Køge, Rødby, the Fehmarn Belt Fixed Link, Puttgarden to Lübeck and via the route E22 to Hamburg. Helsingborg and Hamburg were chosen as starting and ending points because there are important motorway junctions where traffic flows spread to different directions. The total length of the corridor is 424 km and it was divided into six sections under the following aspects:

- important motorway interchanges or junctions as starting or ending points of the sections;
- separation of sections with importance for mainly national or international traffic;
- homogenous traffic flows, junctions to alternative routes (via ferry lines) at starting or ending points of the sections.

Section 1 with a length of 69 km starts in Helsingborg at the junction of Trafikplats Kropp to Malmö West, Trafikplats Fredriksberg, section 2 has a length of 45 km and ends in Copenhagen at the junction of Motorvejskryds Avedøre, section 3 is the longest one with 133 km and ends on the Island of Lolland at junction Maribo, section 4 with a length of 58 km crosses the Fehmarn Belt to junction Heiligenhafen Ost, junction Dreieck Bad Schwartau separates section 5 with 62 km from section 6 which ends after 57 km at junction Kreuz Hamburg Ost.

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[7] See Sec. 6.2.2 with the results of the traffic flow analysis and the share of road freight transports between Sweden and Germany via the corridor.

Figure 4: Possible international ERS-corridor between Sweden, Denmark and Germany with relevant segments (source: own work Intraplan).

6.2.2 Traffic flows on the corridor route

An overview of the methodology and steps of traffic flows analysis is shown in Figure 5, the individual steps are described below.

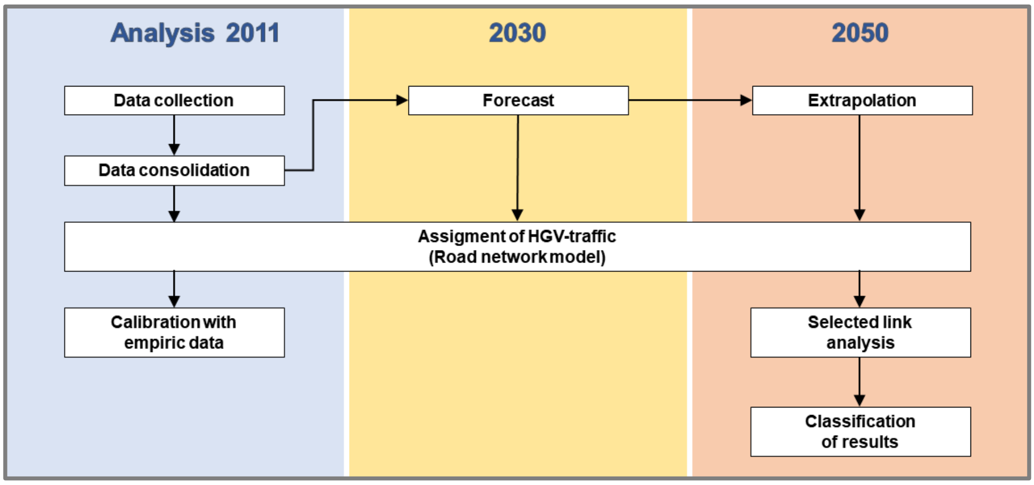

Figure 5: Methodology of traffic flows analysis – Overview of steps (source: own work Intraplan)

Data collection

Traffic flows analysis started with data collection and data comparison – which data concerning transport flows and traffic flows are available in the study area of the potential ERS-corridor? Since the three countries Sweden, Denmark and Germany are concerned by the corridor it was not only necessary to analyse the official statistics of these three countries but furthermore to look for more data concerning traffic flows, e.g. over bridges and via ferry lines to get a picture as full as possible of the transport and traffic flows in the corridor region.

Data consolidation

These data had to be harmonised with regard to base year, zonal levels, vehicle types and commodity groups. Gaps in the collected data were identified and filled up to provide a consistent database of traffic flows for heavy goods vehicles (HGV) per origin-destination pairs (OD on level of NUTS3-zones in Sweden, Denmark, Norway; more detailed in Germany) in the wider study area for the base year 2011.

Table 7 shows the most important data sources used for modelling the traffic flows in the study.

Table 7: Most important transport and traffic flow data

Main source	Traffic flows	Units	Remarks
Fehmarn 2014[8]	DE, EU – DK East, SE, NO, FI, per commodity group	tonnes, vehicles	analysis 2011 and forecast 2030
BVWP 2030[9]	DE – DE, DE – international, transit traffic, per commodity group and NUTS 3	tonnes, vehicles	analysis 2010 and forecast 2030
StratON[10]	DE – DE, DE – international, transit traffic, per commodity group and NUTS 3	tonnes, vehicles	forecast 2030 and 2050, based on BVWP 2030
Danmarks Statistik (statbank.dk)	Domestic traffic flows in DK between provinces per rough commodity group, international traffic between countries	tonnes, vehicles	Yearly, detailed and reliable, no forecast available
Trafikanalys (trafa.se)	Domestic traffic flows in SE between län, international traffic between countries	tonnes, vehicles per county, but no OD-matrix	Yearly, detailed and reliable, processing necessary
Prognos för godstransporter 2040[11]	Domestic traffic in SE, international traffic	tonnes, vehicles per county, but no OD-matrix	analysis and forecast 2040 and 2060

The database for the study covers the following OD traffic-flows:

- International traffic
    - between Germany and the rest of the countries on the Continent on the one side and the Eastern part of Denmark, Sweden, Norway and Finland on the other side[12];
    - also between Denmark and Sweden/Norway; and
    - between southern Sweden and Norway.
- Domestic traffic, in Germany with the region north and east of Hamburg, in Denmark east of the Great Belt and in Sweden with the Skåne län (regional traffic that stays within county Skåne is not included).

Table 8 demonstrates the used data sources in the study per country-based Origin-Destination pairs.

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[8] Intraplan & BVU. (2016). Verkehrsprognose für eine Feste Fehmarnbeltquerung 2014 – Aktualisierung der FTC-Studie von 2002.

[9] BVU, Intraplan, IVV, & Planco Consulting. (2014). Verkehrsverflechtungsprognose 2030.

[10] Öko-Institut, Heilbronn University of Applied Sciences, Fraunhofer IAO, & Intraplan. (2020). StratON: Bewertung und Einführungsstrategien für oberleitungsgebundene schwere Nutzfahrzeuge.

[11] Trafikverket. (2018). Prognos för godstransporter 2040 – Trafikverkets Basprognoser 2018.

[12] This includes transit traffic through Germany, for example from Italy to Sweden.

Table 8: Used data sources per OD-pair

	SE	DE	DK	NO
SE	Trafikanalys (SE)	Fehmarn 2014/BVWP 2030 /StratON	Danmarks Statistik	Trafikanalys (SE)
DE	Fehmarn 2014/BVWP 2030 /StratON	BVWP 2030	Fehmarn 2014/BVWP 2030 /StratON	Fehmarn 2014/BVWP 2030 /StratON
DK	Danmarks Statistik	Fehmarn 2014/BVWP 2030 /StratON	Danmarks Statistik	Fehmarn 2014/BVWP 2030 /StratON
NO	Trafikanalys (SE)	Fehmarn 2014/BVWP 2030 /StratON	Danmarks Statistik	not necessary

Road network model and Assignment of HGV traffic

For assigning the traffic flows to roads, a road network model was set up. It contains not only the important road network in the wider study area of the Scandinavian countries and Germany and its neighbouring countries on the continent, but also the ferry links in the corridor area crossing the Baltic Sea as well as the Kattegat and the Skagerrak. The road network model maps the situation in the base year 2011, as well as it considers future developments in road infrastructure until 2030 and 2050 as assumed in the German Federal Master Plan BVWP 2030 [6] or the study for the Fehmarn Belt Fixed Link [5]. For example, the ferry link over the Fehmarn Belt is assumed to be replaced by the Fehmarn Belt Fixed Link before 2030, the motorway network in Germany is assumed to be expanded further (amongst others A 39 Lüneburg – Wolfsburg, A 14 Schwerin – Magdeburg, A 20 northern bypass of Hamburg with Elbe-crossing).

The HGV traffic flows for the base year 2011 were assigned to the road network for the corresponding base year with a route choice model, taking into account the different characteristics and qualities of alternative routes like length, time and prices. Traffic volumes and chosen routes were calibrated with additional empirical data of ferry links and bridges.

Forecast 2030 and extrapolation 2050

After completion of the forecast traffic flow results for 2030 for the additional OD-pairs not covered by BVWP 2030 and Fehmarn Belt Forecast 2014, the traffic flows were assigned to the road network for 2030 in an intermediate step. In a second step, the traffic flow data for 2030 were extrapolated to 2050 under consideration of traffic growth rates per country OD-pairs derived from the above-mentioned data sources (see Table 7 and Table 8) and as well assigned to the future road network assumed for 2050 which of course also includes the alternative route options like ferry links.

Selected link analysis

The relevant traffic flows via the corridor were identified with a selected link analysis based on the sub-sections between every junction on the corridor. The selected link analysis is a special assignment method that allows not only to quantify the traffic loads on the sub-sections of the road network but also to identify origins and destinations of all traffic flows using the sub-sections. HGV-demand (HGV with more than 12 tonnes and more than 3 axles)[13] per OD-pairs was that way analysed for the whole corridor in total and for its six sections:

- for long-distance HGV (OD-trip-distance more than 100 km),
- thereof long-distance HGV with a trip distance on the corridor-infrastructure of more than 100 km and
- for regional HGV-traffic flows (OD-trip-distance less than 100 km) just as an additional potential for using a possible ERS-infrastructure along the corridor.

Classification of results

For each OD-pair via the ERS-corridor identified in the selected link analysis the following criteria and distances were identified and calculated:

- Distance on the road network from the origin of the OD-trip to the first interchange entering the corridor (**Pre-haul-distance**).
- Distance on the road network from the last interchange leaving the corridor to the final destination of the OD-trip (**Post-haul-distance**).
- Distances for the Main-course – the main-course is the part of the OD-trip between the first interchange entering the corridor and the last interchange leaving the corridor. As the analysis of the traffic flow assignment results and the selected link analysis showed there is a significant number of OD-trips where the corridor is left and re-entered again later by using alternative transport-routes like other roads or ferry links in between[14]. For a calculation of ERS-potentials it was therefore necessary to distinguish between **main-course-distance on the corridor** and **main-course-distance outside the corridor.**

The resulting OD-pairs of the selected-link-analysis were aggregated and classified per distance classes in pre-haul and distance classes in post-haul. On this basis, the suitability of the respective OD-pairs for Battery Electric ERS Vehicles (ERS-BEV) or Hybrid Electric ERS Vehicles (ERS-HEV) is estimated (see section 6.3.1.1).

Results traffic flow analysis for 2050

In the following, the results of the traffic flow analysis are explained for the selected link analysis of the whole corridor.

Table 9 shows the results of the traffic flow analysis for the whole corridor in detail – per distance classes in pre-haul and post-haul as described above.

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[13] The following descriptions of the results always refer to HGV with weight of more than 12 tonnes and more than 3 axles if not mentioned different.

[14] For example, an OD-trip from Hamburg to Gothenburg can use the corridor from Hamburg to interchange AD-Lübeck-Bad Schwartau, using the ferry-link between Lübeck-Travemünde and Trelleborg outside the corridor, and re-enter the corridor at the interchange Malmö-Petersborg till Helsingborg.

Table 9: Results traffic flow analysis 2050 – long-distance HGV (weight > 12 t, > 3 axles, OD-trip-distance > 100 km) on any part of the corridor

Main course				Pre-haul		Post-haul	
number of HGV-trips per day	HGV-distance on the corridor (km/day)	HGV-distance outside corridor (km/day)	share of HGV-distance on the corridor	distance class (km)	HGV-distance (km/day)	distance class (km)	HGV-distance (km/day)
5 578	276 343	356	99.9%	up to 100	168 947	up to 100	176 608
3 812	113 386	3 904	96.7%	up to 100	50 882	101 – 250	685 237
2 474	138 273	7 566	94.8%	up to 100	47 290	251 – 500	945 047
2 524	120 440	18 168	86.9%	up to 100	38 160	from 501	1 938 860
3 924	122 514	3 123	97.5%	101 – 250	699 730	up to 100	51 270
403	28 909	3 951	88.0%	101 – 250	66 494	101 – 250	67 104
332	26 923	31 263	46.3%	101 – 250	60 123	251 – 500	128 833
351	25 959	33 453	43.7%	101 – 250	64 490	from 501	359 087
2 606	152 523	29 850	83.6%	251 – 500	983 593	up to 100	46 703
336	28 822	31 735	47.6%	251 – 500	132 161	101 – 250	60 064
315	27 025	37 165	42.1%	251 – 500	115 736	251 – 500	134 298
783	66 978	87 388	43.4%	251 – 500	294 776	from 501	784 633
2 513	130 259	62 406	67.6%	from 501	2 095 950	up to 100	41 875
487	33 071	30 710	51.9%	from 501	449 913	101 – 250	91 287
503	48 219	71 545	40.3%	from 501	460 990	251 – 500	211 104
1 461	123 561	104 538	54.2%	from 501	1 418 110	from 501	1 433 187
28 402	**1 463 205**	**557 121**	**72.4%**	**Sum**	**7 147 345**	**Sum**	**7 155 197**

In 2050, HGV traffic will use the corridor on any part for more than 28 000 trips per day (see the bottom line of Table 9), no matter for which distance, with a traffic performance of nearly 1.5 million kilometres per day along the corridor and about 0.6 million kilometres per day on the main course but outside the corridor (on ferries or other roads). Traffic performance in pre-haul and post-haul is each more than 7.1 million kilometres per day. This yields to (in the table not shown) average trip distance on the electrified corridor of more than 50 km, plus 20 km for traffic in the main course but outside the corridor and of more than 250 km for each in pre-haul and post-haul. Average trip distance in total for HGVs using the corridor on any part is more than 570 km.

An evaluation of the results per OD-pairs on level of countries shows that 95 % of the road freight traffic with HGV between Sweden and Germany will use parts of the corridor – on any section, with different trip lengths on the corridor. Table 9 shows the traffic flows via the corridor in the study area resulting from the selected link analysis.

The highest loads of HGV traffic along the corridor can be found on sections where traffics of different routes and where national and international traffics overlap, in Sweden from Helsingborg to Malmö, in Denmark south of Copenhagen, and in Germany between Lübeck and Hamburg.

The significance of alternative transport routes along the corridor is also visible, for example on the ferry lines from Lübeck-Travemünde to Trelleborg and from Rostock-Warnemünde to Trelleborg. The traffic flows via these ferry lines use parts of the corridor, e.g. from Hamburg to Lübeck or from Malmö to Helsingborg.

Compared to the results of the traffic flows analysis in the German StratON-project [7], it can be concluded that the traffic potentials along the corridor referring to HGV-trips are mostly lower than examined for the possible ERS-motorways in Germany. Nevertheless, the share of long distances in international traffic is much higher than in national traffic, therefore international traffic is an interesting potential for ERS and reduction of GHG emissions in road transport, especially for traffic between Sweden, Denmark and Germany with its large concentration to the corridor.

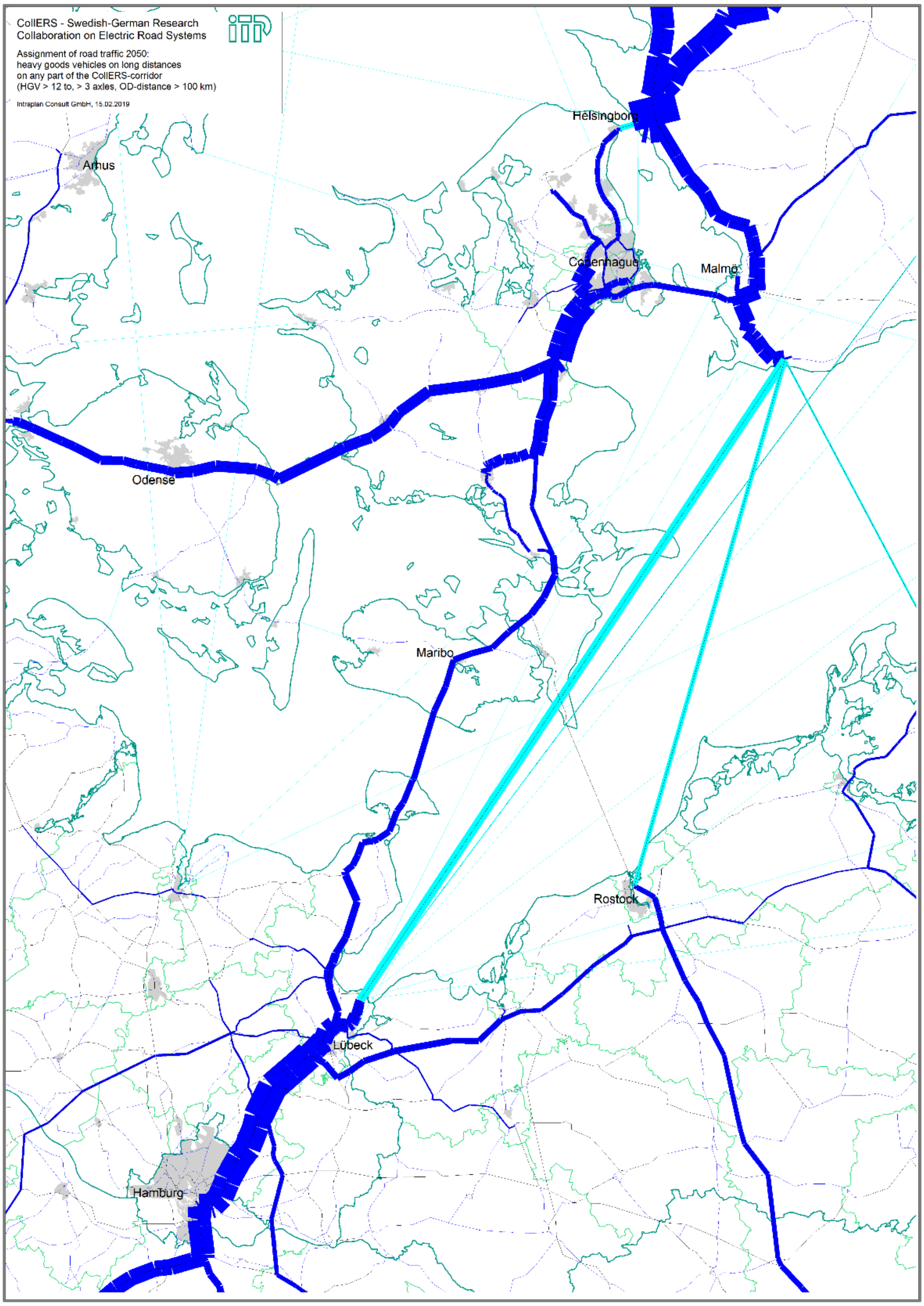

Figure 6: Assignment of road traffic 2050 – HGV (weight > 12 t, > 3 axles, OD-trip-distance > 100 km) on any part of the CollERS-corridor (source: own work Intraplan)

Additionally, the usage of the corridor by regional HGV-traffic flows with OD-trip-distances of less than 100 km was analysed for the whole corridor and per section. The additional potential for using a possible ERS-infrastructure by regional traffic flows amounts for the whole corridor to 5 140 HGV-trips per day and to over 200 000 HGV-kilometres per day in the main course on the corridor.

6.2.3 EU freight corridors adjacent to the corridor route

In order to assess the potential future role of a Swedish-German ERS corridor as well as possible expansion scenarios, it is important to look at adjoining long-haul freight corridors. For the corridor route, the following adjacent routes with relatively high traffic loads have been identified and are discussed in more detail below:

- in Sweden from Helsingborg along the E4 in direction to Stockholm and along the E6 northwards to Gothenburg as well as the short stretch of the E6 from Malmö to Trelleborg,
- in Denmark the E20 from Køge westwards to Odense and Jutland, and
- in Germany the E22 from Hamburg via Bremen in direction to the Rhein-Ruhr-area.

Adjoining freight corridors in Germany

The corridor on the German side follows the A 1 from Denmark via Lübeck to Hamburg, and thus runs along the Scandinavian-Mediterranean Ten-T corridor and is connected to the Ten-T network. Therefore, there are good possibilities to continue a possible extension directly on the Ten-T corridors. In addition, the corridor ends in Hamburg, an important freight transfer point and junction of several important trunk roads.

When considering the German motorway network and the Ten-T corridors, the following four expansions options are obvious from a network perspective:

1. A 1 from Hamburg via Bremen in the direction of the Ruhr area (287 km)

2. A 7 from Hamburg via Hannover towards Kassel (286 km)

3. A 24 from Hamburg in the direction of Berlin (227 km)

4. A 20 from Lübeck towards Rostock (120 km)

The route options are shown in Figure 7. Our corridor is marked blue, the route options are marked red and Ten-T corridors are shown in yellow. The routes 2 and 3 are both completely part of the Ten-T network. The part of route option 1 between Hamburg and Osnabrück is not included in the Ten-T network (dotted), but connects further Ten-T corridors at Bremen. The section from Osnabrück to the eastern edge of the Ruhr area is then again included in the Ten-T network. Route option 4 is not part of the Ten-T network (dotted).

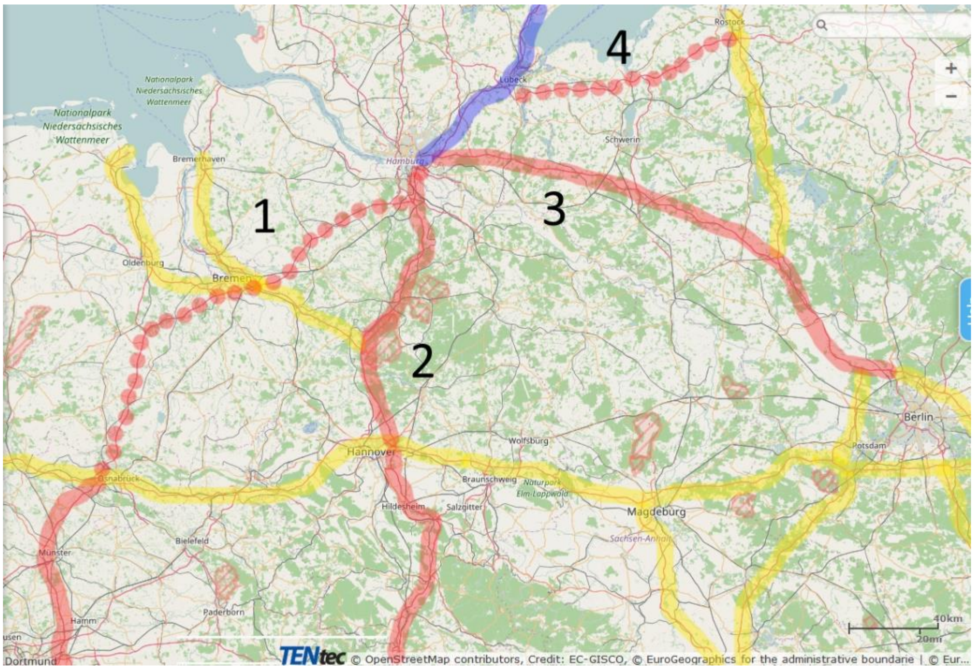

Figure 7: ERS Corridor route and adjoining TEN-T corridors in Germany (source: own work Öko-Institut based on Ref. [9]

Which route would be the most feasible one from a traffic point of view, can be derived by considering the direction and intensity of the traffic. It has to be decided whether the focus lies exclusively on the German-Swedish transit traffic or also on the other freight traffic on the German motorway network. In addition to the traffic flow analyses of the corridor (Section 6.2.2), the StratON project [7] also provides analyses for the above-mentioned routes 1 to 3 in the German motorway network. Option 4 was not examined in detail due to the comparatively low traffic volume.

In the CollERS project, the same criteria were used for the route analyses as in the StratON project (truck weight > 12t, >3 axles and travel distance >100km on the overhead line network). In addition, regional traffic on the ERS corridor of less than 100 km total distance has been evaluated.

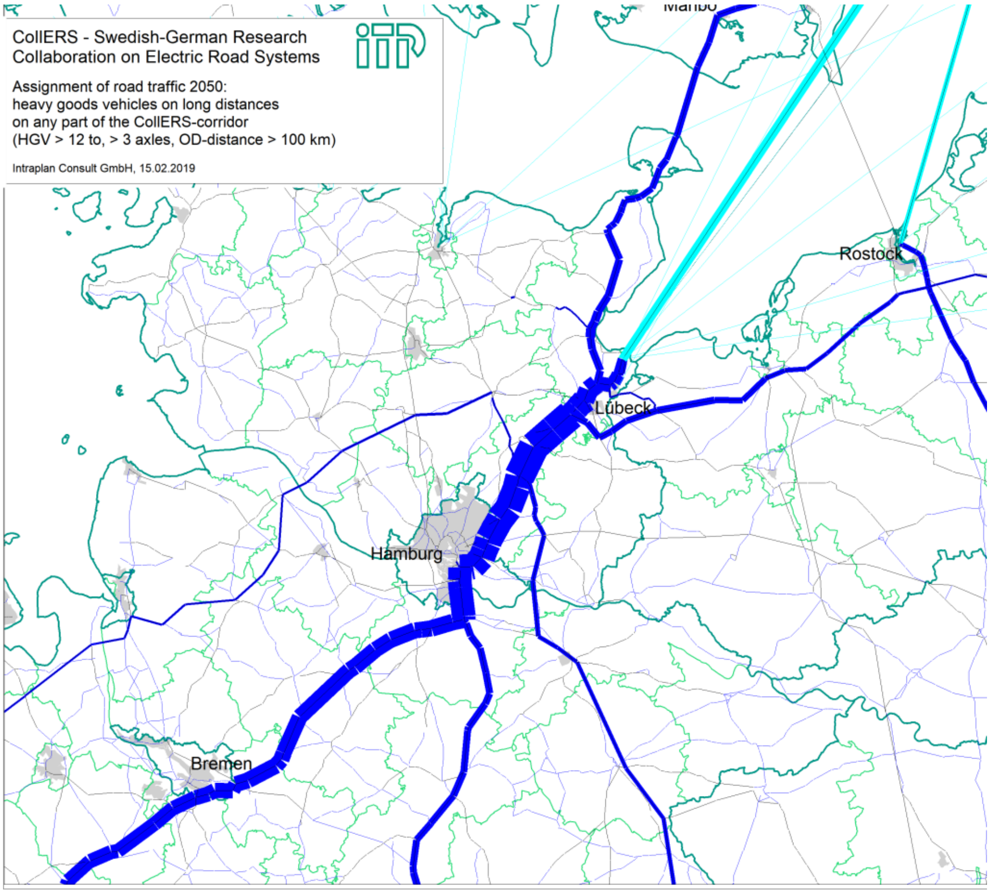

Figure 8: Distribution of traffic flows from the ERS corridor onto adjoining routes on the German side, using selected link analysis (source: own work Intraplan)

The traffic analyses carried out in the StratON project for inner-German traffic show high suitability for ERS, especially for the A 1 and A 7 from Hamburg to the Ruhr area and Kassel respectively and lower suitability for the A 24 from Hamburg to Berlin.

The A 1 has the highest average daily traffic (ADT) with 6.3 million vehicle kilometres, followed by the A 7 with 5.4 and the A 24 at a clear distance with 2.6 million vehicle kilometres. On the A 1, more than 50 % of the journeys are longer than 100 km. In terms of pre- and post-haulage, the A 1 to the Ruhr area also has the highest proportion of journeys (31 %) with less than 250 km pre- and post-haulage. In addition, the connection to the Ruhr Area offers an important link to international freight corridors in the future (see also Figure 11).

In this context, the A 1 from Hamburg to the Ruhr area is a particularly suitable extension option for the German-Swedish corridor being analyzed. In principle, the possible alternatives also show that Hamburg, in general, has high potential as a starting point for a route extension due to its importance in international freight traffic.

Analyses that take into account the entire corridor including the proposed extension route and thus also cross-border transport are necessary to further specify the potential for ERS on this corridor.

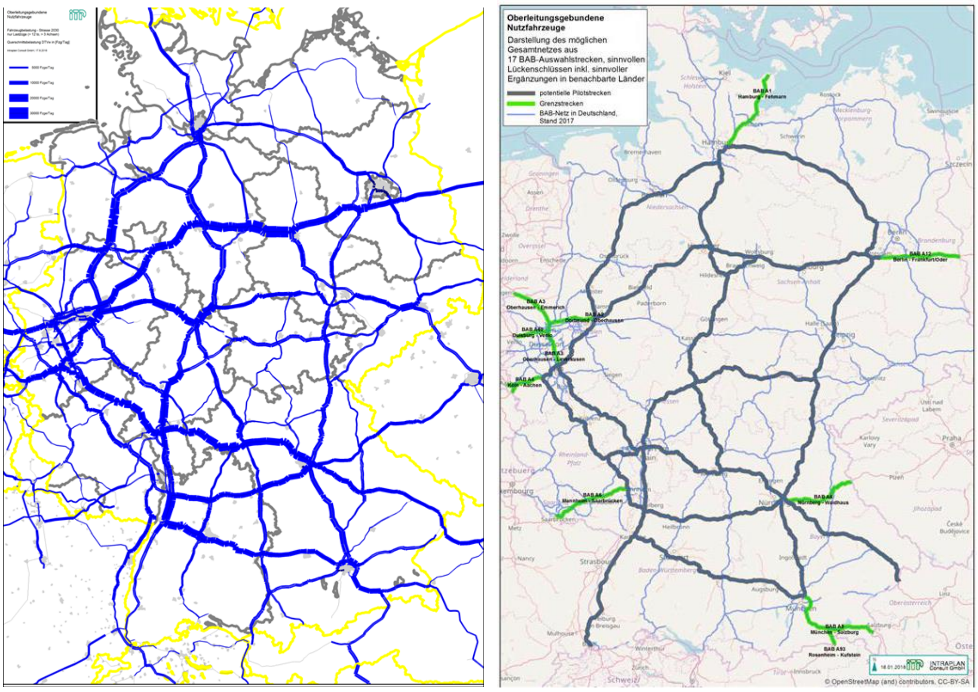

Figure 9: StratON project [7]: projected traffic volumes on motorways for trucks with more than 4 axles in 2030 (left); possible ERS network in Germany with international connections (right)

Adjoining freight corridors in Sweden

Considering adjoining freight corridors for heavy road traffic connected to the proposed ERS corridor on the Swedish side yields two immediate promising candidates:

- road E6 from Helsingborg toward Gothenburg and
- road E4 from Helsingborg to Stockholm.

These two road stretches today are the most traffic-intensive parts of the Swedish road network, with the E4 between Helsingborg-Stockholm constituting 11 % of the total heavy vehicle traffic nationally in Sweden while the E6 between Malmö-Gothenburg currently holds 6.5 % of the national heavy traffic [10]. The HDV traffic volumes on these roads resulting from ERS-suitable traffic on the ERS corridor are shown in Figure 10.

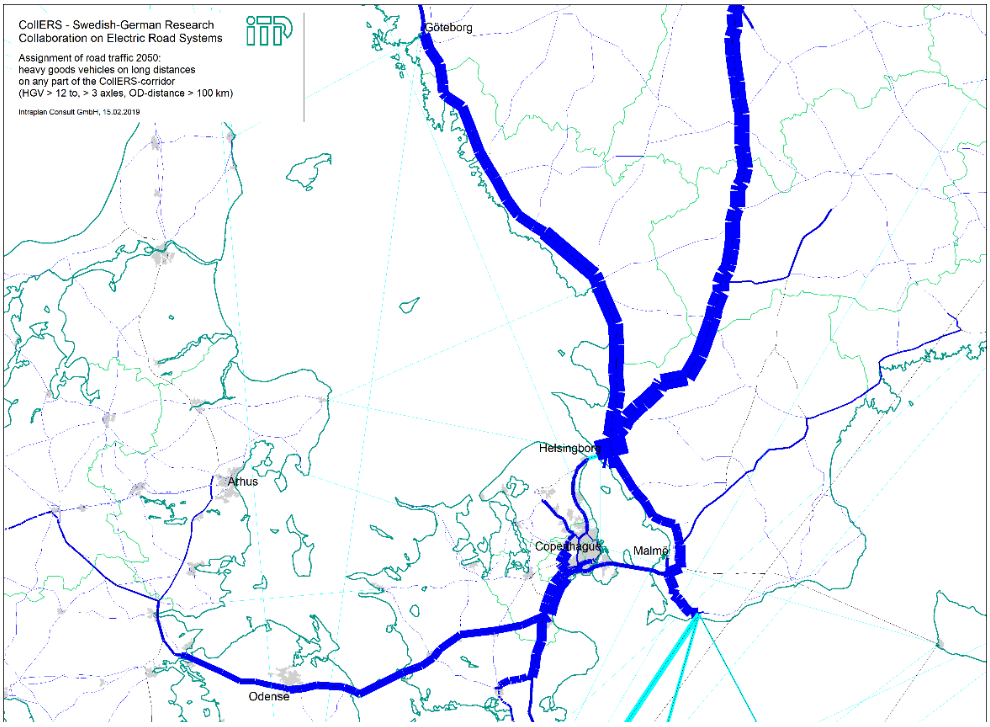

Figure 10: Distribution of traffic flows from the corridor onto adjoining routes on the Swedish side, using selected link analysis (source: own work Intraplan)

Part of road E6 (Malmö-Helsingborg) is already included in the corridor, and a possible ERS continuation on the E6 could go either to Gothenburg or possibly be extended all the way to Svinesund. Prolonging electrification of E6 to Svinesund would mean this stretch covers 10 % of all heavy traffic in Sweden [11]. All road traffic data is based on average daily values and were obtained from the Swedish Transport Administration.

Figure 11 shows that the E6 between Malmö-Gothenburg has a consistent average daily traffic (ADT) for heavy vehicles above 2000, along with parts of the E4 between Helsingborg-Stockholm. The rest of the E4 between Helsingborg-Stockholm has a consistent heavy vehicle ADT between 1500 and 2000. If all heavy vehicles travelling upon these roads are electrified through ERS, this would mitigate GHG emissions of roughly 1.2 million tonnes CO_2 equivalents/year, corresponding to 6.5% of the total yearly GHG emitted from the entire transportation sector in Sweden [10].

There is currently no significant expansion or major future changes planned for these roads, apart from local improvements to reduce traffic congestion and improve capacity for both light- and heavy vehicles on the E6 in Gothenburg and the E4 in Stockholm [12].

Official forecasts from the Swedish Transport Administration project a general increase of heavy vehicle transport of 1.3 % per year between 2014 and 2040 on the Swedish road network (Trafikverket 2018b). In this projection, there is a disparity between heavy vehicles without trailers (estimated 0.9 %/year increase) and heavy vehicles with trailers (estimated 1.8 %/year increase). No specific projections for roads E4 or E6 are available as of now.

Road E22 was also screened as a potentially important freight corridor, starting in the city of Malmö and stretching eastward along the southern Swedish coast towards Kalmar and ultimately Norrköping. Average daily traffic data from the Swedish Traffic Administration showed that E22 holds approximately the same level of heavy vehicle traffic volumes as the E4 and E6, but only between Malmö and Lund. After Lund, the traffic intensity of the E22 is reduced, reaching a 50 % reduction after only 40 kilometres (by the city of Hörby) which then continues at this intermediate traffic intensity level for much of the continuation of the road. Thus, road E22 was deemed to not be in the same area of importance as road E4 and E6 when it comes to freight transport and a subsequent national ERS rollout in Sweden.

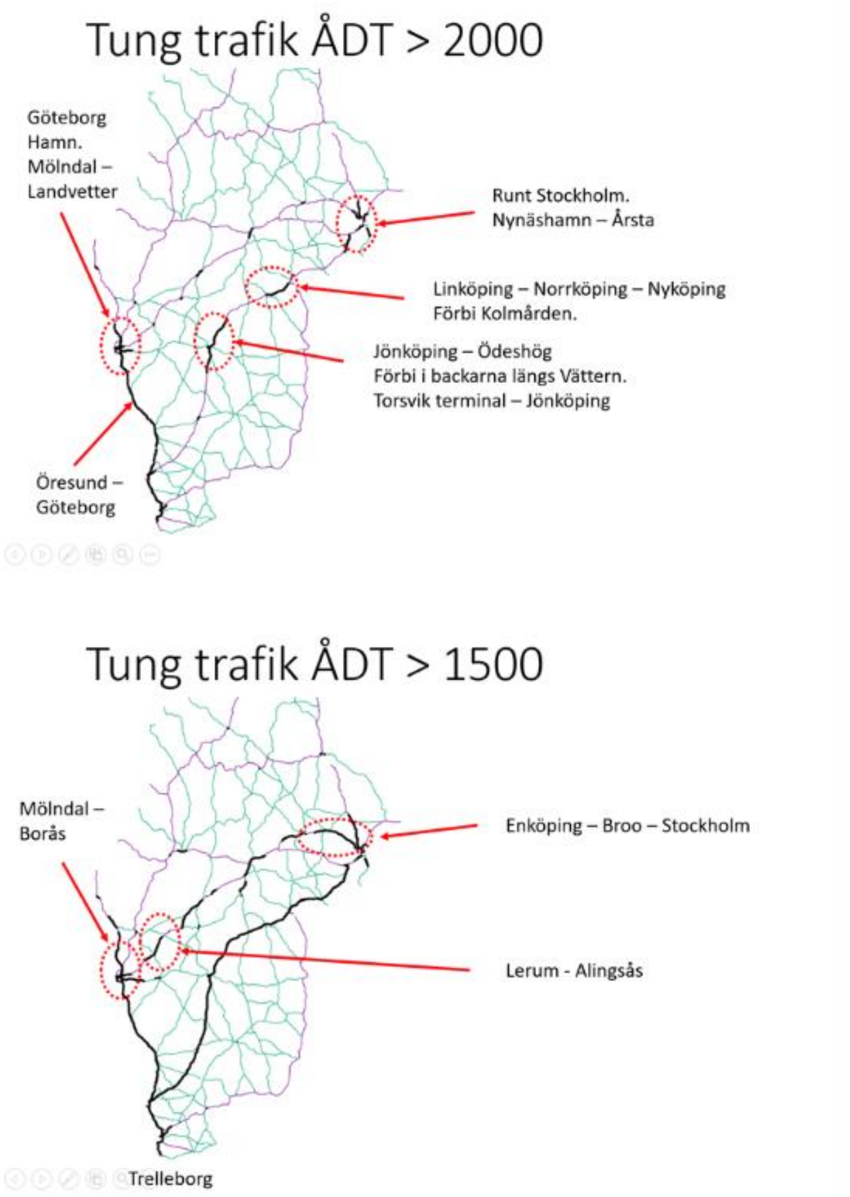

Figure 11: Parts of the Swedish national road network exceeding heavy vehicle ADT numbers of 2000 resp. 1500. Data from the Swedish national road database [13]

This analysis was based on general traffic data, and there might be a case for electrifying road E22 (or other roads close to the corridor) based on other merits such as special freight conditions, e.g. major industry that pledges to use ERS on specific road stretches outside the corridor itself.

6.3 Application of assessment methodology to Exemplary Corridor Route

The previously described Swedish-German transport corridor is in this section evaluated using the technical, economic, environmental, and political criteria defined by this study (see Sec. 2).

6.3.1 Technical Criteria

6.3.1.1 Possible electric mileage

An ERS only makes sense if it enables vehicles to operate on electricity, thus saving fossil fuel, and have to be compared with other fossil-free alternatives. In the following, based on the traffic flow analysis in Sec. 6.2.2, the electric mileage which can be reached by vehicles using the corridor is calculated. In turn, the achievable GHG reductions and possible effects on air quality along the corridor depend on the electrical mileage. The share of the electric mileage of an individual ERS vehicle also has a direct influence on the economic efficiency of the vehicle from the operator’s point of view. It therefore also influences the contribution that a vehicle operator can pay to refinance the infrastructure.

In the traffic flow analysis, we classified the traffic flows on the corridor based on their pre- and post-haul distances outside the corridor. We now use this classification to select which traffic volumes that could be handled with ERS-capable vehicles.

More thorough analyses are needed in order to determine traffic volumes which are realistically suitable for ERS. The study of this section is thus not meant as a comprehensive feasibility analysis, but rather as application example for the assessment methodology.

In line with the StratOn project [7], we use the following criteria as a basis:

- In the traffic flow analyses, only mileages were considered which are covered by vehicles with more than 12-tonne gross vehicle mass and more than 3 axles.
- If both the pre- and post-haul distances are less than 250 km, it is assumed that an ERS vehicle can operate on the corresponding relation. This limit comes primarily from economic considerations of the vehicle operators.

The limitation on the pre- and post-haul distances results in a subset of 45 % of the total truck mileage on the corridor. In absolute terms, this means 232 million km per year on the corridor and a further 777 million km travelled by the same vehicles outside the corridor. On average, the share of mileage on the corridor route for an individual vehicle would therefore be about 22 %. However, this percentage may largely vary according to the routes of the individual vehicle.

Routes with pre- and post-haul distances up to 100 km and regional traffic with a total route length of less than 100 km account for a significant share of the potential electric mileage on the corridor with about 63 % of all electric mileage.

In addition, the pre- and post-haul parts could also be driven on electricity by these vehicles. However, it has to be examined for every particular case whether a certain route can be operated by purely electric vehicles with a given battery size. It has to be kept in mind that, depending on the vehicle configuration (battery size), ERS vehicles can, in principle, also drive at least partially by electricity outside the ERS infrastructure.

Furthermore, for shorter overall trip distances, we can expect an increasing suitability for pure battery electric trucks. Generally speaking, there will be a trade-off between costs for the vehicle-side ERS components, costs for additional battery capacity, and the cost of using ERS compared with the cost of using stationary charging. Future research needs to further investigate under which conditions regional freight traffic could benefit from lower operating costs by using an existing ERS.

Table **10: Key figures regarding potential HGV mileage along the corridor fulfilling basic criteria, i.e. weight > 12 t, > 3 axles, and pre- and post-haul distances < 250 km. Traffic flows could not be reliably determined for section 1 of the route with the chosen approach, see further explanations in the text. Regional mileage is defined as the sum of HGV trips with individual routes less than 100 km. All mileages are given in million kilometres.**

	Total HGV mileage on corridor	Mileage of trips fulfilling basic criteria			Share of mileage fulfilling criterai from total mileage	Mileage pre-/post-haul of critera fulfilling trips	Share of operation on corridor
		on corridor	thereof pre-/post-haul < 100 km, but total distance > 100 km	thereof regional			
Section 1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Section 2	37	24	3	8.0	65 %	49	33 %
Section 3	152	109	54	35.7	71 %	176	38 %
Section 4	30	6	0	0.2	21 %	25	20 %
Section 5	41	17	2	5.1	41 %	70	20 %
Section 6	140	45	11	12.1	32 %	141	24 %
Total corridor	**500**	**223**	**77**	**61**	**45 %**	**777**	**22 %**

The results differ considerably when looking at the individual route segments. Table 10 summarizes the main parameters for the individual sections. Particularly in the Copenhagen area (sections 2 and 3), the total transport performance per route kilometre is high on the one hand, while at the same time there is a high proportion of traffic with relatively short total distances and thus low pre- and post-haul distances. The highest share of trips with pre- and post-hauls less than 250 km along the corridor can be found on sections where traffics of different routes and where national and international traffics overlap, in Denmark south of Copenhagen and in Germany between Lübeck and Hamburg.

For Denmark south of Copenhagen and in Germany between Lübeck and Hamburg (sections 3 and 6),

For section 1, there have been some issues with data symmetry compared to the other sections. This is mainly due to the fact that section 1 is rather short, but the resolution of traffic cells in Sweden is lower than for the other countries. Thus, regional traffic is significantly underestimated for section 1 and trips are not quantified for this section. However, some qualitative remarks regarding section 1 can be found in section 6.2.3 of this report.

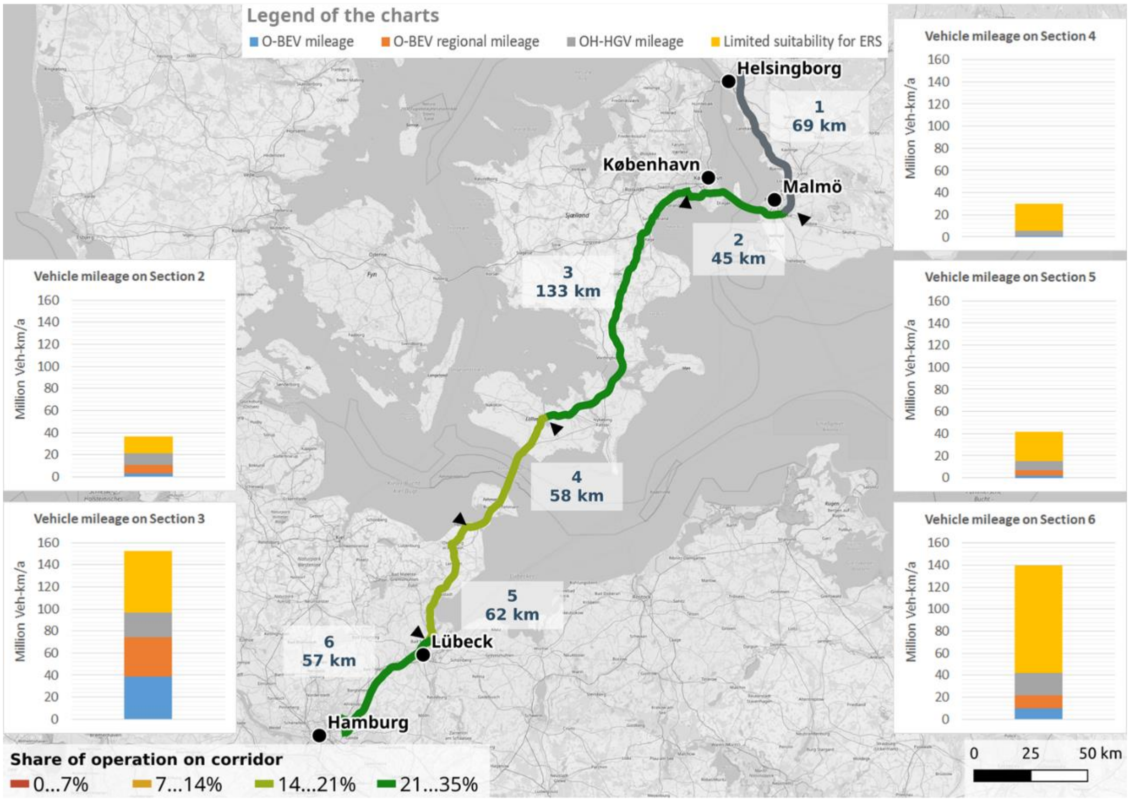

Figure 12: ERS suitability on the corridor (source: own work ifeu)

The existence of ERS infrastructure on important access routes to the corridor (both on the German and on the Swedish side) could make it feasible for ERS vehicles to operate on routes which have a longer pre- or post-haul distance beyond the ends of the corridor. Thus, synergies can be expected between the international corridor and the expansion of the respective national networks.

6.3.1.2 Availability of electricity supply

The selected corridor route from Sweden to Germany in large parts runs through East Denmark. Namely it is the highway from Copenhagen to Rødby. Therefore the analysis of energy supply from the electricity grid to a possible ERS has a focus on Denmark, which so far has not been covered by the respective national projects of CollERS.

Results of the ongoing German project “Roadmap OH-Lkw” suggest that a connection of each rectifier to the local medium voltage grid is not realistic. The analysis therefore assumes a megavolt (MV) cable running parallel to the ERS which is fed by the high voltage grid on several locations. This parallel cable needs to be fed every 30–50 km. Therefore planning is quite flexible and the MV cable can be connected to suitable knots in the high voltage grid. Hence, a detailed analysis of the medium or high voltage grid is not necessary.

In Denmark the grid can handle a high share of wind power and the feed-in of these plants exceeds the load at many times. Because of the high infeed the grid is much stronger than required by the load, so a moderate additional load is considered to propose no challenge. At times of high wind generation an additional load will even reduce stress in the grid.

To get an idea of the potential additional load, the potential energy demand of the ERS was calculated and compared with other loads and generation types. Figure 13 shows the power demand of ERS in total of East Demark (Zealand) as calculated for a representative week by the Scope model, which was also used for the comparison of the Swedish and German energy system within the CollERS project [14]. In the following calculation only the ratio between the maximum power consumption of ERS and its average is used and assumed with 1.79:1 (60.1 MW/ 33.9 MW, see Figure 13). On the corridor the highest ERS traffic is assumed on section 3 (see Figure 4), which covers 133 km and is most of the route in Zealand. Hence, the results of section 3 are used for the assessment.

One of the basic assumptions in the traffic flow analysis was that routes with a maximum distance of 100 km beyond the ERS corridor are in principle suitable for operation with ERS battery trucks (i.e. purely electric). This holds particularly for regional traffic with limited overall distances and possibly explicit future zero-emission requirements in urban areas. According to the results in Section 6.3.1.1, the mileage on section 3 will be about 109 million km per year, whereof about 90 million km would be allotted to routes with less than 100 km pre- and post-haul, which are assumed to be operated by all-electric ERS vehicles. Further assumptions for the following analysis of the grid impact are documented in Table 11.

Table 11: Assumptions for power consumption of truck running in section 3 of the ERS corridor

Truck operation	Power consumption	Energy consumption	Distance per year	Yearly energy consumption
Driving in flat terrain, no charging at 82 km/h	110 kW	1.34 kWh/km	19 million km	25 GWh
Driving in flat terrain incl. charging at 82 km/h	220 kW	2.68 kWh/km	90 million km	241 GWh

Under these assumptions, the total energy consumption of section 3 is 266 GWh per year. This results in an average power of 30.4 MW for the whole section or 229 kW per kilometre. The peak power consumption is now estimated based on the ratio between peak and average power of 1.78:1 from the Scope model (as mentioned above). Accordingly, the peak demand would be 54 MW for the entire section 3 or 408 kW per km.

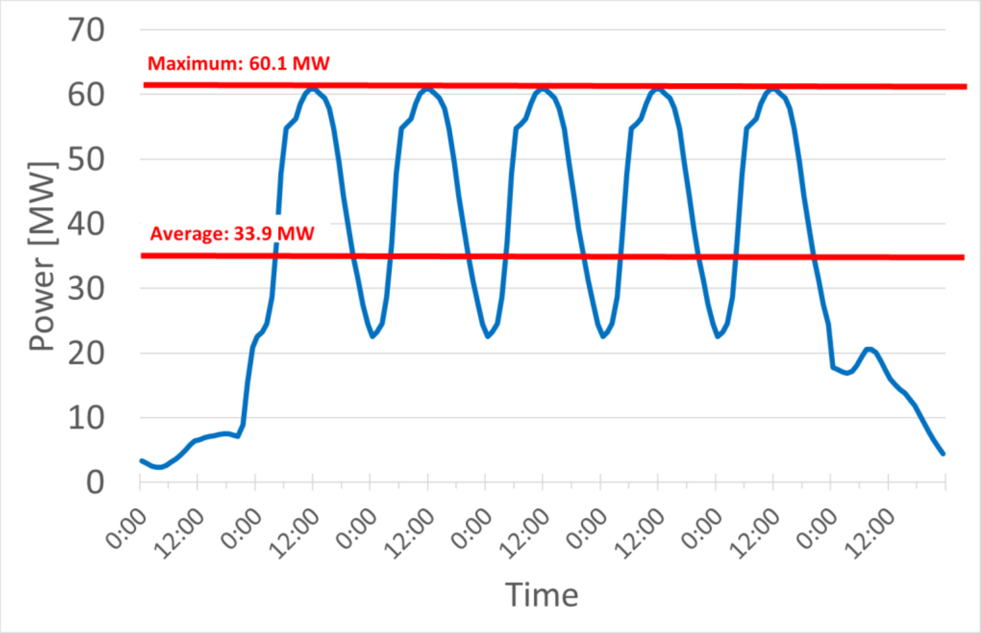

Figure 13: Power demand of the electric road systems in East Denmark (Zealand), example week from energy scenario calculations (Scope model, own calculations Fraunhofer IEE).

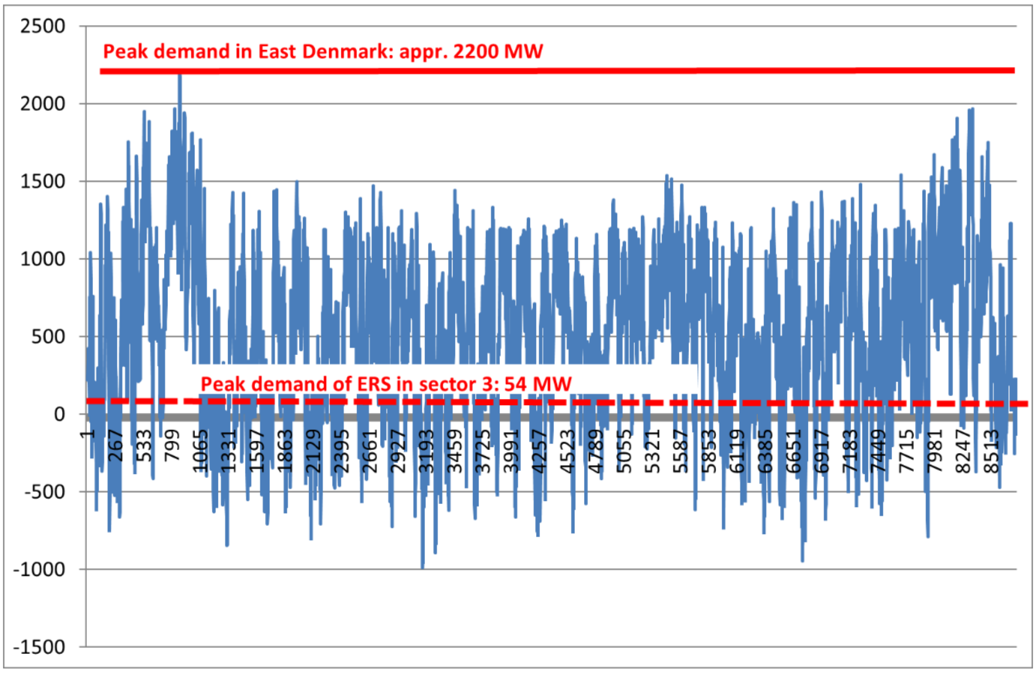

Figure 14: Residual load in East Denmark for a full year derived from the Scope model (own calculations Fraunhofer IEE).

The ERS peak demand of 54 MW in section 3 can now be compared to the residual load in East Denmark with a peak power of up to 2200 MW as shown in Figure 14. Even at peak times the ERS power demand is only in the range between2 and 3 % of the total peak load. Although the project does not allow for a detailed grid analysis, it can be stated that is it very unlikely that this additional load would cause any issues in the high voltage grid.

6.3.1.3 Interoperability

Regarding the maturity and availability of standards, it should initially be stated that there are still no published or draft standards dedicated to electric road systems neither on a Swedish, German, European nor global standardisation level. Therefore, it is presently not possible to pinpoint standards that have an officially confirmed significance for ERS in general or for the corridor in particular.

For the moment though, standards are discussed as a prerequisite or facilitator of ERS introduction. In this context, some existing standards, which have originally been created for other adjacent purposes like tramways or railway operation, could potentially be adapted for ERS.

In the European Committee for Electrotechnical Standardization (CENELEC), two new work items dedicated to ERS have recently been added within CENELEC TC9X (CLC/TC 9X - Electrical and electronic applications for railways). This demonstrates that railway standards have as to yet been the point of departure for the relatively recent ERS standardisation discussions within CENELEC. The new work items are

- "Technical Requirements for Current Collectors on Commercial Road Vehicles in Overhead Contact Line Operation", (CENELEC TC9X WG 27) and
- "Current collectors for ground-level feeding system on commercial road vehicles in operation" (CENELEC TC9X, SG).

Since ERS are rather composed of several different systems, issues of "interface standardisation" can have different meanings depending on the focus. From sampling the current view among European ERS stakeholders, the most common interpretation of interface standardisation seems to be the creation of interfaces which allow several ERS (sub)solutions (vehicles, ERS, grid) within one country/system [15]. Specifically, the interface conflicts mentioned by stakeholders related to the vehicle/road infrastructure interface and road/electric power supply interface.

Further issues of ERS in addition to such standardisation are:

- Upward interoperability: Resolving ERS interface conflicts on an even higher system level, which is inter-State ERS interface conflicts. Can standardisation aid a smooth shift-over for prospective large volumes of international transports between future different ERS systems in different countries?
- Downward interoperability: This means standardisation on a minor system scale, i.e. solving ERS interface conflicts within a certain system component area and within a specific ERS technology. Accordingly, can standards guarantee for example that all vehicles can connect to various conductive technical solutions within the same country, and furthermore, within the frames of a certain technology, say for rail-in road charging?
- Horizontal interoperability: Compatibility/interoperability between systems created for instance for light vehicles and buses and ERS. Taking the example of charging infrastructure, it is already now questionable whether standardisation can aid interface conflicts between dynamic versus static charging infrastructures. There are already standards for static charging of vehicles, but these are likely to be not compatible with future requirements

> for ERS and dynamic charging. The questions would thus be: Is there a future where certain ERS technology could be used both for dynamic and static charging of various vehicle types?

With regard to the ERS corridor, we can conclude that questions in the area of standardization may pose major challenges to such a project. Given the complexity of standardization, it cannot be expected that first large-scale ERS implementations will be built on an entirely finalized set of standards. However, large-scale ERS projects might in turn develop a momentum that helps accelerating the standardization process.

6.3.2 Environmental Criteria

6.3.2.1 Reduction of climate gas emissions

The main objective of the introduction of ERS is the effective reduction of CO_2 emissions. In the following, we calculate the possible CO_2 reduction caused by an ERS corridor due to electric vehicle operation. The scope is "Well-to-wheel", i.e. it includes the emissions during vehicle operation and the upstream emissions to provide diesel and electricity. Vehicle manufacture, maintenance and disposal as well as the provision of infrastructure, however, are not part of the analysis.

For the calculation, we assume that the electric mileage derived in Section 5.1.1 will be realised. Furthermore, we assume a hybrid-ERS vehicle with only a small traction battery, so we can make the simplifying assumption that the vehicle will only use electric mode while on ERS.

There are major differences in the provision of electricity between the countries involved in the corridor (see Table 12). In Sweden, hydropower and nuclear energy contribute a large part of electricity generation, each with a relatively low CO_2 emission factor. In Denmark the electricity generation system consists of between 40 and 50 % wind power, with the rest consisting of central power plants burning coal or biomass, along with a small share of solar power (Energinet.dk 2018). In Germany, in addition to a share of renewable energies in electricity generation of about 38 % in 2018 [16], there is currently a considerable share of coal-fired electricity in the grid, which significantly increases the CO_2 factor compared with the other two countries.

Table **12: Projected carbon intensity of electricity production in the corridor countries in 2030 [17].**

Country	**Projected CO2 factor 2030** [g CO2/kWh]
Sweden	40
Denmark	155
Germany	310

All three countries are striving to expand electricity generation from renewable energies. Germany has also agreed in principle to phase out electricity production from coal completely by 2038 [18]. With regard to a possible ERS corridor, the year 2030 can be roughly considered as the earliest realistic point in time for the start of ERS operation on the corridor and is thus used as the reference year for assessment of CO_2 emissions. The specific emission factors for 2030 have been determined on the basis of official government forecasts (not taking into account an accelerated phase-out of electricity generation from coal in Germany, since the respective law is still under negotiation) and are also shown in Table 12. The specific emission factors for 2030 have been calculated on the basis of official government forecasts. For the calculation of the CO_2 reductions, it is assumed that the electricity consumption is divided among the individual country mixes according to the ERS corridor section length within the respective country.

The supply of diesel fuel is also expected to change by 2030. European regulation will not induce significant change in biofuel shares until 2030 [19]. However, a shift is expected from cultivated biomass fuels towards fuels from residual materials. On the other hand, the Swedish government wants to increase the share of biodiesel in fuel sales by national measures to 50 % by 2030 [20]. Since long-haul diesel trucks usually have a long range of between 1000 km and 2000 km without refuelling, it can be expected that for international transports the companies will go to the pump in countries where diesel is cheapest. Since this is currently Germany, we assume refuelling in Germany as the base case.

Figure 15 shows the total CO_2 emissions (well-to-wheel, i.e. electricity and fuel production is included) of HDV on the corridor route, assuming that all ERS-suitable OD pairs are actually operated by ERS vehicles (see section 6.3.1.1) . In total, there is a CO_2 reduction potential of 117 kt CO_2 equivalents per year in 2030 for the ERS corridor. If the electricity supply for the corridor would be carbon-neutral, the reductions would rise to 153 kt.

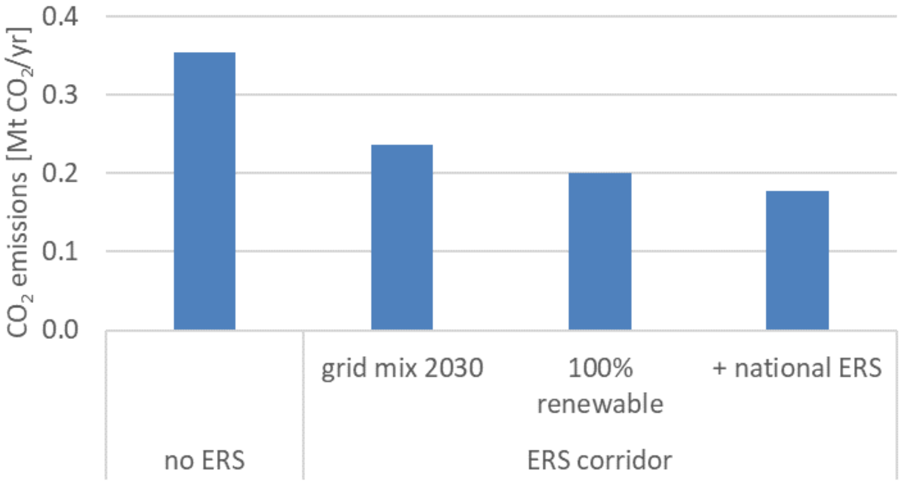

Figure 15: Total CO_2 emissions (well-to-wheel) by HDV on the corridor route (based on estimated electricity mix in 2030). Source: Own calculations ifeu.

If the participating countries would roll out national ERS networks in parallel to the ERS corridor project, we can principally expect synergies. Based on the case described in Section 5.1.1, the CO_2 reduction through electrical operation on the corridor would then rise to a total of 175 kt.

The reductions per electrified road kilometre differ considerably for the individual sections of the corridor (see Figure 16). They are highest in the Copenhagen area, where there is a high overall traffic volume and moderate specific emissions from electricity supply.

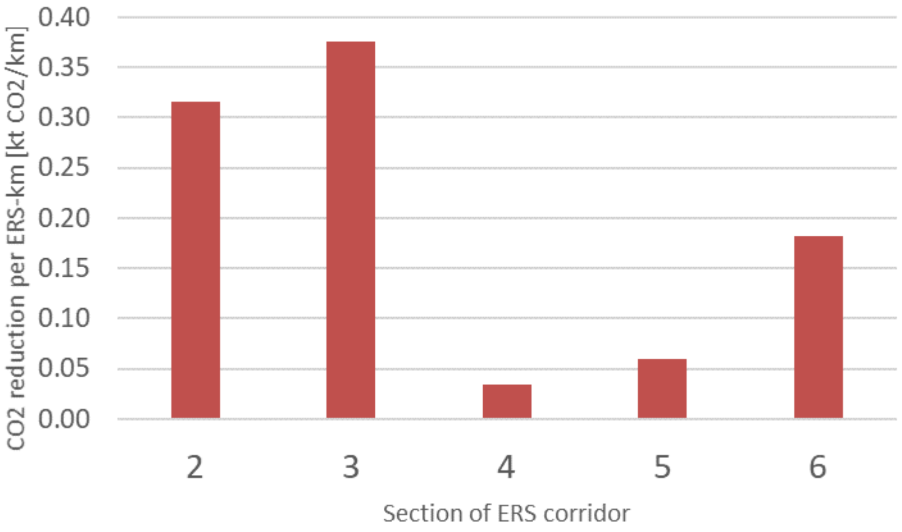

Figure 16: CO_2 reduction per electrified road-km (based on estimated electricity mix in 2030). Source: Own calculations ifeu.

6.3.2.2 Improvement of air quality

In terms of air quality, especially particulate matter (PM) and nitrogen dioxide (NO_2) concentrations show frequent exceedances of limit values in densely populated areas[15] and may have relevant impacts on human health. These exceedances are often observed close to streets with high traffic volumes and are thus at least partly due to road transport emissions. The electric engine fully avoids PM and NO_2 emissions from the tailpipe, which can potentially have very positive effects of ERS on air quality. This effect, however, will have a limited impact on the critical urban air quality situation due to several reasons.

First of all, road transports in general and heavy trucks in particular make a limited contribution to urban concentrations, especially since the ERS corridor mostly leads through extra urban areas. This can be illustrated with the example of the H.C. Andersen' Boulevard in Copenhagen (see Figure 17).

The regional NO_2 emissions – which would mainly benefit from regional ERS systems - contribute only 17 % to urban NO_2 concentrations, while further 8 % are due to the urban background. In total, however, only 8 % of the background concentration is attributable to road transport at all. Thus, especially local traffic contributes to the urban NO_2 concentrations (69 %) and 23 % can be attributed to local truck traffic. Here ERS trucks can make a relevant contribution towards NO_2 reductions only if the vehicles are designed to also use their electric drive outside the ERS corridor (e.g. if they are equipped with a larger battery).

The situation is somewhat different for PM_{10} concentrations. Here the contribution of regional sources to urban concentrations is generally higher, but road transport is only one out of many PM emission sources. Therefore, only slightly above 1 % of the

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[15] Along the ERS corridor, these are mainly Hamburg and the Copenhagen/Malmö area.

total concentration at an urban street with high traffic volumes is therefore due to a road transport background. Even though the share of local vehicle emissions is relevant, these are mostly due to other vehicle types and also resuspension, brake abrasion and tyre wear, which can be expected to be similar for ERS. The share of truck exhaust emissions on urban PM concentrations is thus negligible.

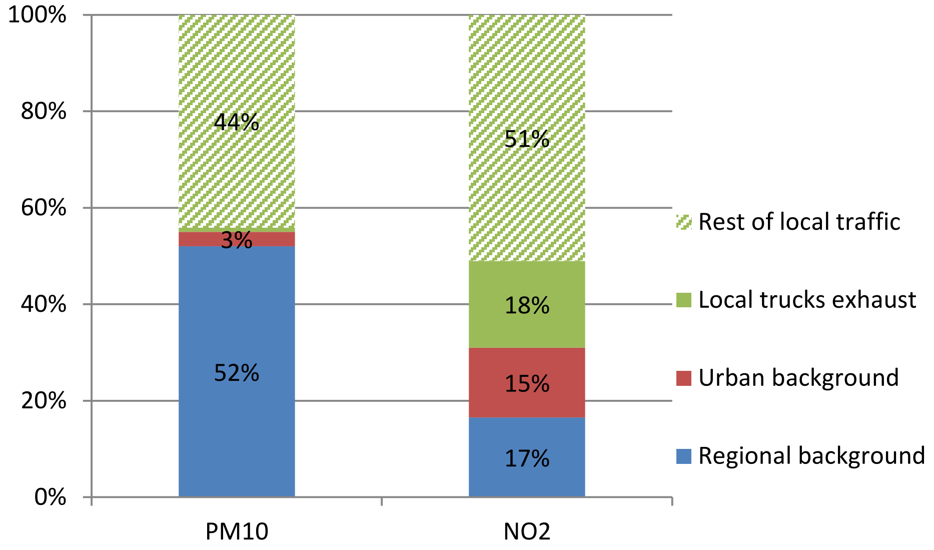


Figure 17: Sources contributing to concentration on H.C. Andersen' Boulevard in Copenhagen (The Danish Ecological Council 2014)

On the contrary, it has to be assessed if there will be wear and tear from the physical power transfer connection potentially leading to additional particle emissions in the case of catenary lines. The type of particles will depend on the materials used as well as pressure from the power receiver device. Heated cables will produce more wear than colder cables and worn down or damaged cables will in turn damage the carbon strip of the pantograph leading to further particle emissions. Schulte mentions the ecotoxicity that might come from overhead catenary ERS. In the LCA comparison of fast chargers and overhead catenary ERS it was found that the ecotoxicity levels were much higher for ERS than for fast chargers [21].

This could be somewhat avoided if batteries are charged along ERS road sections in rural areas and use their batteries when driving in or through cities. Particles will, nevertheless, instead affect soil and water quality of rural areas and again the effects will depend on which kind of ERS concept is being used. Also, in-road conductive ERS technique will be worn down from the use of the pick-up as well as from passing vehicles. How much or what type of particles will be emitted is yet to be investigated. Only the inductive techniques will not produce any extra particle emissions since these kinds of technology does not depend on physical contact.

It should also not go unmentioned that electric operation comes along with a potential shift of emissions from the tailpipe (and refineries) to power plants. Here also electricity generation by coal and gas fired power plants will still lead to relevant emissions today, even though the share of renewable is generally increasing. This is generally considered to be more relevant in respect to GHG emissions since their impact is independent of the location of emissions. For pollutant emissions, exposure of the public also depends on the location of the source. Power plants are usually located away from the current air quality hot spots, but might nevertheless contribute to the background concentration. In the case of Copenhagen, however, the contribution of power plants and other incineration facilities is considerable lower than the share of road transport: 0.2 % contribution to the background concentration for PM_{10} (compared to 2.3 % for road transport) and 8.3 % for NO_2 (compared to 25.8 % for road transport). These effects are therefore not likely to compensate potential positive effects of zero emission driving.

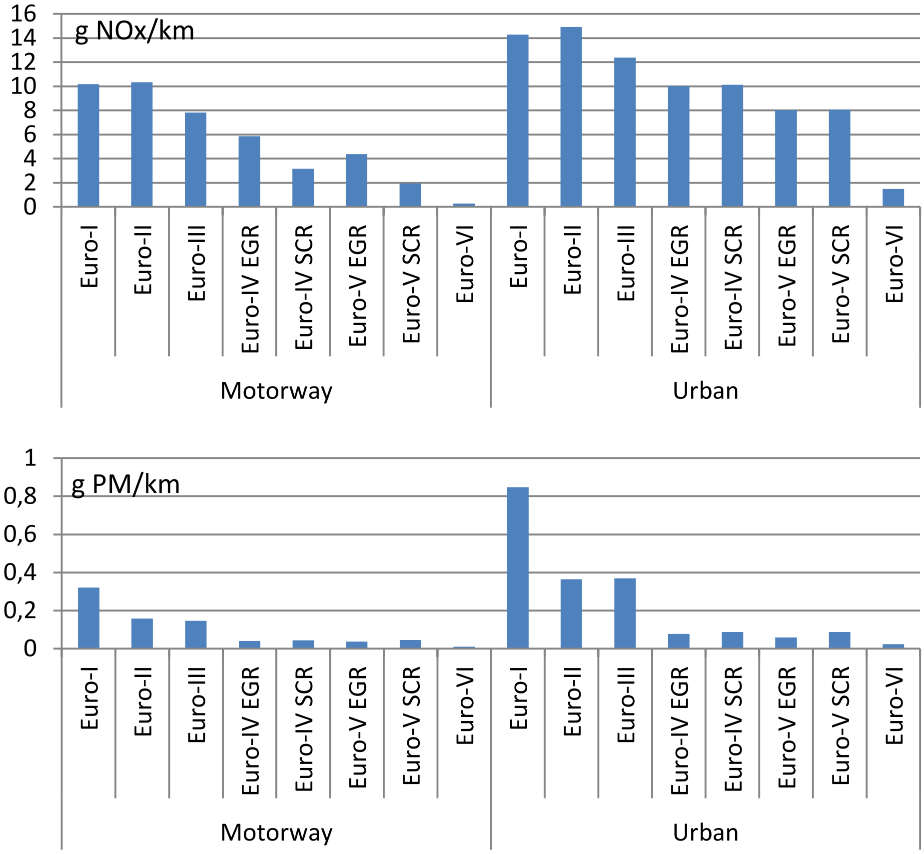


Figure 18: Real world emissions of heavy trucks (40 t GVW) according to HBEFA (Matzer et al. 2019)

Finally it must be mentioned that modern Euro IV trucks are assessed to have a considerably improved emission behaviour compared to older generation trucks (see Figure 18). While PM emissions have already been reduced considerably with the introduction of Euro IV, for NOx emissions especially Euro VI is believed to bring a significant further emission reduction, especially in urban areas. Road transport and especially the contribution of diesel trucks to PM and NO_x concentrations can therefore be expected to decrease in the future regardless of the introduction of ERS. The additional benefit of ERS in electric operation will therefore rather decrease in the years to come.

Overall it must be concluded that even though there are some potential air quality benefits associated with ERS, these will be rather small. To make a relevant contribution towards improved air quality in the coming years, a short term roll out will be necessary. Furthermore, it will be important that ERS trucks also operate with electric drive within the urban areas, e.g. by having a sufficient battery capacity.

6.3.2.3 Reduction of noise emissions

Road vehicle noise is basically consisting of the noise from the engine, the wind draft and the contact between wheels and road surface. At higher speeds noise from the wheel on the surface increases and dominates. On motorways (such as will be used for ERS) the speeds are mostly above 30 km/h, which is approximately when the wheel/surface noise is louder than the noise from combustion engines (Danish Road Directorate 2015). Hence, there are probably no significantly different noise levels of ERS on the motorway. However, there might be additional noise stemming from the interaction of pantograph and cables as well as pick-up and rails. This could potentially lead to lower noise levels for inductive technology.

So far there have only been a few tests performed and more studies are needed to quantify the impact. Two different demonstration sites in Sweden have carried out noise measurements which, however, are not entirely comparable making interpretation difficult. One of the reports suggests that the noise from the interaction of the pick-up and the conductive ERS can also be higher than the noise from the vehicle.

- From the E16 eHighway [22] project in Sweden the noise measurements have been undertaken at different speeds and showed a reduction in noise emission by 3 dB when using electricity compared with combustion engine, for speeds up to 50 km/h.
- Noise measurements of the eRoad Arlanda project [23], where the electricity is provided conductively using a rail in the road surface and a pick-up arm beneath the vehicle, in contrast was undertaken at a constant speed of 65 km/h. At this speed noise emissions where the same as for the reference truck or a bit higher. The higher noise emissions where found when the pick-up was passing a joint or during arcing. Arcing occurs when the power transfer is unintendedly interrupted, causing a light flash. Obstacles such as leaves, or ice might cause such interruptions that generate arcing and this phenomenon applies to all kinds of conductive energy transfer.

It is not mentioned in the E16 project whether they included arcing in their study or not. Nevertheless, the lower noise levels that can be detected at lower speeds will not be noticed at speeds over 50 km/h. Any reduction in the noise level due to ERS will hence only be effective in cities or congested areas where the speeds are limited to under 50km/h. Further noise measurements are needed to understand the influence of the drag of the pantograph or pick-up on the ERS.

Considering noise emissions along the proposed corridor, ERS might contribute in lowering the noise levels in congested urban areas along the corridor. There are, however, still uncertainties regarding the drag noise of the conductive ERS techniques.

6.3.3 Economic Criteria

6.3.3.1 TCO advantage of operators

The following TCO analysis is from the operator's point of view (forwarder, independent driver, etc.), since it is assumed that the infrastructure will be publicly financed in an early phase and that operators only have to pay the toll according to the current legislation. In this context a profitable operation of the ERS truck means that the total costs associated with procurement, depreciation, operation and maintenance of the ERS vehicle are lower than the costs of a comparable conventional truck.

The considered "Total Cost of Ownership" (TCO) is calculated for semitrailer tractors. The cost assumptions are based on the overhead catenary ERS technology, since figures for this technology are more reliable than for other technologies as of now. All payments are exclusive of VAT and are standardised as real figures for the year 2017. Costs for maintenance, vehicle, driver and other fixed costs are assumed equal for the three considered countries. Regarding energy prices (diesel and electricity) as well as tolls, national values are used which also consider specific taxes or fees.

Vehicle costs are calculated on the assumption that the vehicle is purchased at the beginning of its service life and sold again after 5 years. The vehicle is financed by an annuity loan with an effective interest rate of 4.5 %. The residual value of the vehicle is calculated as a percentage of the purchase price and in the simplified model only depends on the mileage of the tractor unit within the operating period. The residual value of the ERS vehicle is derived from conventional tractors. The same relative depreciation is assumed for both technologies.

Energy costs depend on diesel and electricity prices as well as energy consumption and are considered separately from other variable costs based on national values. The Diesel price for Germany in 2020 is based on own estimations based on the Reference Technology Scenario of the IEA and statistics from Refs. [24] and [25]. The Diesel prices for Denmark and Sweden are taken from Ref. [26] (msverige.se 2019). The given values represent the prices in 2019. For the year 2020 it is assumed that they rise proportionally to the German Diesel price. The electricity price for Germany is again based on own assumptions. Denmark's and Sweden's prices are given by Refs. [27] and [28]. While the conventional vehicle is operated exclusively with diesel, for the ERS truck it is also relevant whether a stretch of road is electrified and therefore traction can be carried out with electricity from the grid. In addition to this distinction, the road category is also important, as the consumption of a vehicle depends to a large extent on the type of road. The calculation simply distinguishes between toll roads without ERS, toll roads with ERS and non-toll roads. The most relevant assumption of the TCO calculations are summarised in Table 13.

Table 13: Assumptions for vehicle price, mileage, fuel economy and energy prices in 2020

	ERS truck	**Conventional truck**
Purchase price	164 000 €$_{2017}$	98 000 €$_{2017}$
Residual value after 500,000km	54 400 €$_{2017}$	33 500 €$_{2017}$
Annual mileage	100 000 km/year	
Annual mileage on toll roads	76 000 km/year	
Fuel economy** – toll road	27.2 l/100 km (Diesel drive) 129 kWh/100 km (Electric drive)	31.4 l/100 km
Fuel economy** – other roads	25.9 l/100km	31.0 l/100 km
Costs (excluding vehicle, energy and toll)*	59 100 €$_{2017}$/year	57 200 €$_{2017}$/year
Diesel price (Denmark-Germany-Sweden)	1.62 (D); 1.09 (G); 1.70 (S) €$_{2017}$/l	
Electricity price (Denmark-Germany-Sweden)	29 (D); 18.8 (G); 14 (S) ct$_{2017}$/kWh	

** including financing, taxes, insurance, fees, administration, garage, driver, lubricant, tyres, maintenance, AdBlue, etc.; ** based on own simulations*

Since ERS trucks tend to have higher fixed expenditures compared to diesel trucks, but lower operational expenditures in electric mode, the proportion of operation on ERS is a crucial assumption. With an annual mileage of 100 000 km of which 38 % are assumed to be using ERS (i.e. 50 % of toll roads, 38 000 km annually), the operation would be already profitable in Germany and Sweden in the short term perspective (see Figure 19). The potential savings are higher in Germany, since here a toll exemption for electric vehicles is currently in place until 2023 which would be effective for ERS vehicles (as well as for all other electric trucks) regardless of their actual operation on ERS infrastructure. This cost advantage would make operation of ERS trucks profitable in almost all use cases from an operator's perspective, regardless of the existence of an ERS system.

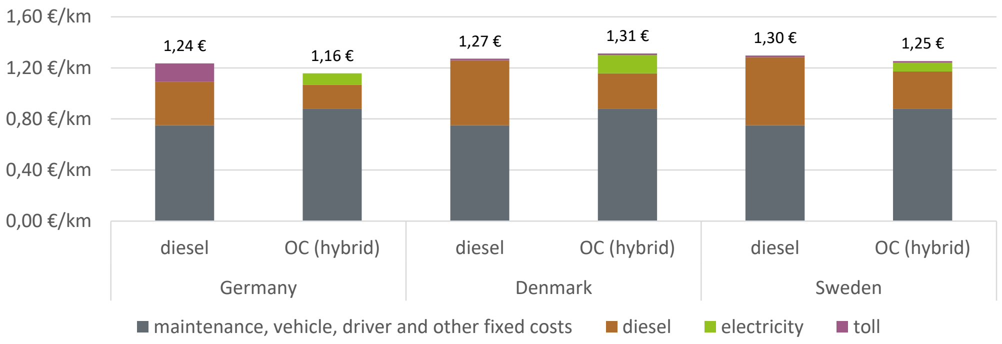


Figure 19: Total Cost of Ownership for diesel and ERS hybrid trucks in 2020 (according to assumptions in Table 13 and current legislation)

In Sweden and Denmark, ERS trucks would currently pay the same toll as EURO VI trucks and therefore do not have this comparative cost advantage.

In Denmark, operation of ERS trucks would currently not be profitable due to the considerable higher electricity prices than in Germany and Sweden. The cost difference at 4 ct per km, however, is currently also low and within the expected uncertainty range.

Several factors might change in the mid-term. Vehicle costs can be expected to decrease with scaling-up of ERS technology, making ERS trucks more competitive. These price developments can be expected to become effective in all three countries along the corridor in a European vehicle market. In terms of operational costs, there are uncertainties regarding the development of energy prices (which are also affected by national taxes and fees) as well as road tolls.

The above-mentioned results are valid for current conditions, assuming an ERS corridor would already have been built and ERS vehicles would be available on the market. However, both of these assumptions will take some years to be realized; particularly, an ERS corridor project of the dimensions considered should be expected to take about ten years for planning and construction. We therefore also take a look at the year 2030. A scenario for the development of electricity prices until 2030 was available for Germany, but no corresponding scenarios could be found for Denmark and Sweden. Therefore, a quantitative discussion of the potential future TCO is undertaken for Germany only based on the data summarised in Table 14.

Table 14: Assumptions for vehicle price, mileage, fuel economy and energy prices in 2030

	ERS truck	Conventional truck
Purchase price	139 000 $€_{2017}$	98 000 $€_{2017}$
Residual value after 500,000km	45 000 $€_{2017}$	33 500 $€_{2017}$
Annual mileage	100 000 km/year	
Annual mileage on toll roads	76 000 km/year	
Fuel economy** – toll road	24.3l/100 km (Diesel drive) 121kWh/100 km (Electric drive)	27.8l/100 km
Fuel economy** – other roads	23.0l/100km	25.9l/100 km
Costs (excluding vehicle, energy and toll)*	63 000 $€_{2017}$/a	61 800 $€_{2017}$/a
Diesel price (Germany)	1.26 $€_{2017}$/l	
Electricity price (Germany)	13.8 ct_{2017}/kWh	

** including financing, taxes, insurance, fees, administration, garage, driver, lubricant, tyres, maintenance, AdBlue, etc.; ** based on own simulations*

In Germany the current exemption of electric trucks from road tolls is scheduled to end in 2023, which would significantly affect the cost situation if no further exemption is enacted. In terms of energy prices, the assumed increase of the diesel price would have less effect on the TCO of the ERS truck, which would also benefit from an assumed decrease of electricity price. This, however, would be compensated by road tolls if no further exemption is enacted (Figure 20). Besides uncertainty in the energy price development, especially the question of road tolls will be an important factor determining the future cost advantages for operators at least in Germany.

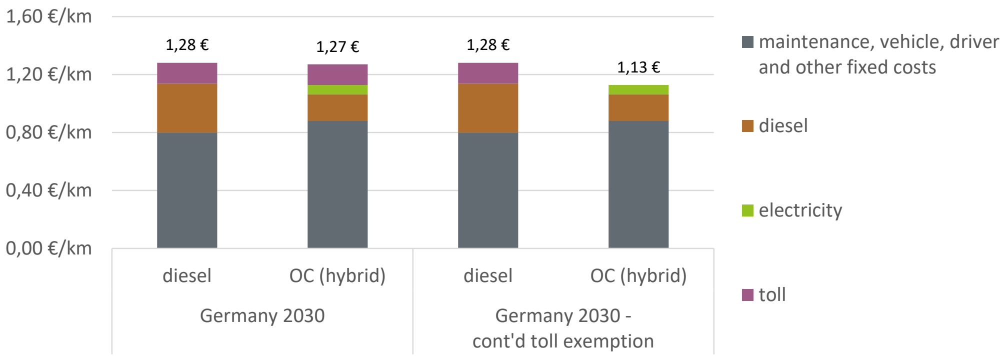


Figure 20: Potential Total Cost of Ownership for diesel and ERS hybrid trucks in Germany in 2030

6.3.3.2 Expected cost balance of an ERS corridor

In this section, we establish a cost balance of the chosen Swedish-German ERS corridor, including investment and operational costs for ERS infrastructure and vehicles. A robust, well-functioning and properly dimensioned infrastructure is necessary to enable the electrification of transportation through ERS, but also associated with great up-front costs. These can vary with a number of factors, for example choice of ERS technology, intensity of traffic that connects to the ERS, level of dimensioning, scalability etc. The design of the ERS infrastructure, determining many of these parameters is still object of research and testing on current and future ERS test-sites. Thus, the following estimation of the ERS cost balance is subject to considerable uncertainties and can only serve as an indication in order to highlight important aspects.

The Swedish Transport Administration has together with the consultancy EY developed a modelling tool for highlighting the costs of infrastructure, operation and maintenance of ERS. This tool has then been used in a national perspective in Sweden to gain insight into how different price parameters affect the system costs of different ERS scenarios, and how a possible roll-out of ERS technology could look in terms of its costs and benefits [29]. The following results for the investigated corridor are based on this approach.

6.3.3.2.1 Method and assumptions

The cost calculations in the model reflect the current cost of operating heavy vehicle transportation using diesel fuel as the baseline comparison. As energy costs for electric drive is generally lower than for diesel operation, the cost difference of switching heavy vehicles to run on electricity acts as the margin of cost savings that can be used to fund other parts of the ERS system, such as infrastructure investments. How big this margin is, and how much investment is needed depends on the examined ERS scenario. All cost estimations presented refer to a bi-directional ERS, i.e. ERS technology deployed along one lane in one direction plus one lane in the opposite direction.

The projected **cost of deploying the infrastructure** of an ERS network is based on a number of current cost estimates:

- Construction of wayside ERS infrastructure, for example connections between the ERS and the regional electricity grid. Estimated cost: 0.4 to 0.8 M$€_{2019}$/km.

- Construction of ERS infrastructure, for example ERS power transfer technology between the road and the vehicle. Estimated cost: From 0.94 to 1.87 M€$_{2019}$/km.
- Construction of roadside ERS infrastructure necessary for safe operation, for example road guardrails. Estimated cost: From 0.05 to 0.47 M€$_{2019}$/km.

The most recent estimates of the total infrastructure cost of ERS (comprising these three aspects) thus lie in the range from 1.73 to 3.1 M€$_{2019}$/km according to the Swedish Transport Administration. The range of the expected investment of ERS infrastructure depends on several factors, most importantly the choice of ERS technology (catenary, conductive rail or inductive). The cost estimations have been derived from several reports [29], results from ongoing ERS pilots and in dialogue with different ERS actors. For the following analysis, we assume costs for ERS and roadside infrastructure of 1.8 million € per ERS-km (which represents an average for different ERS technologies) and costs for extension of electricity grid of 0.58 milion € per ERS-km.

Apart from infrastructure, the system cost balance further includes:

- **Investment in vehicle conversion** for ERS compatibility (in terms of heavy trucks). The additional cost per vehicle are estimated at 34 000 €, which implies a series production of this technology.
- **Energy costs** for heavy trucks. Here, the values for year 2020 from Sec. 6.3.3.1 are used.

6.3.3.2.2 Results for system cost balance

The cost model described above is applied to the Swedish-German ERS corridor described in Sec. 6.2.1. In the case of complete electrification of the route (424 km), the annual payment flows shown in Figure 21 are obtained. The most important cost items are the additional costs for ERS-compatible vehicles and the electricity costs. The infrastructure costs depreciated over their lifetime, on the other hand, are comparatively lower and the estimated costs for necessary extensions of the electricity grids significantly lower. On the other hand, we can expect revenues which are essentially determined by the energy cost advantage of ERS truck operators. Additionally, there might be several factors that affect the price ERS truck operators are willing to pay for operation of the technology. For example, they might want to have additional revenues to compensate for the risk associated with the introduction of ERS as a novel technology. On the other hand, there might be business models where additional revenues can be generated by offering environmentally-friendly transports.

In the following, we assume that the same energy costs as for conventional vehicles will be tolerated, so the potential revenues correspond to the saved expenses for diesel fuel. This makes it necessary to establish a funding scheme which at least partly covers the additional costs of the truck operators for the ERS vehicles. The costs for such a funding scheme could for example be covered by the potential revenues in turn. However, in the following we solely look at the overall cost balance and neglect questions of cost allocation.

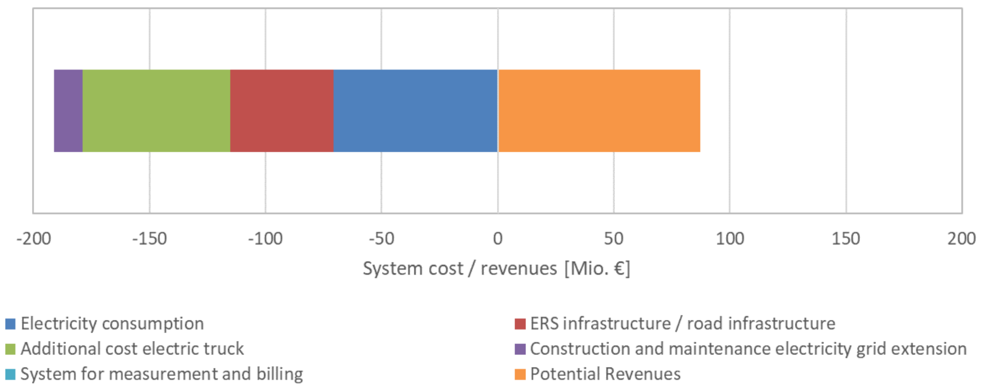


Figure 21: Estimated break-down of annual system costs of a Swedish German ERS corridor (full electrification)

The regulatory status quo was assumed for the underlying cost structure. As a reference year, we assume 2030 since this is the time when the ERS corridor considered here could possibly enter operation.

In total, the operation of the ERS corridor results in significant annual additional costs of about 100 million € per year in 2030. In addition, the participating states are expected to lose around 30 million € in revenue from energy taxes. This result makes it clear that, under the current framework conditions, considerable financial support would be necessary at least in the short to medium term to implement an ERS corridor. In view of the risks with regard to technology and acceptance among operators, it is to be expected that the participating states would have to play a leading role in this respect.

On the other hand, an ERS corridor should lead to considerable reductions in greenhouse gas emissions (see section 6.3.2.1). If ERS is to be utilized as an instrument of climate protection, the expected CO_2 abatement costs are therefore an important parameter. Figure 22 shows the potential CO_2 reductions and the corresponding CO_2 abatement costs (excluding tax revenue). Different assumptions are used as a basis: On the left, the reduction potentials are shown for the case that the entire corridor is implemented; on the right, only Section 3 is electrified, which has the highest potential for ERS suitable mileage among all the sections considered (see Section 6.3.1.1). For each of these two cases, three sensitivities are shown:

- "Average": The energy prices as well as the CO_2 intensity of the electricity generation correspond to the respective route section of the ERS (international sections are calculated proportionately).
- "SE": energy prices and electricity generation for the whole ERS route are based on the Swedish situation.
- "GE": For energy prices and electricity generation the German situation is used for the whole ERS route.

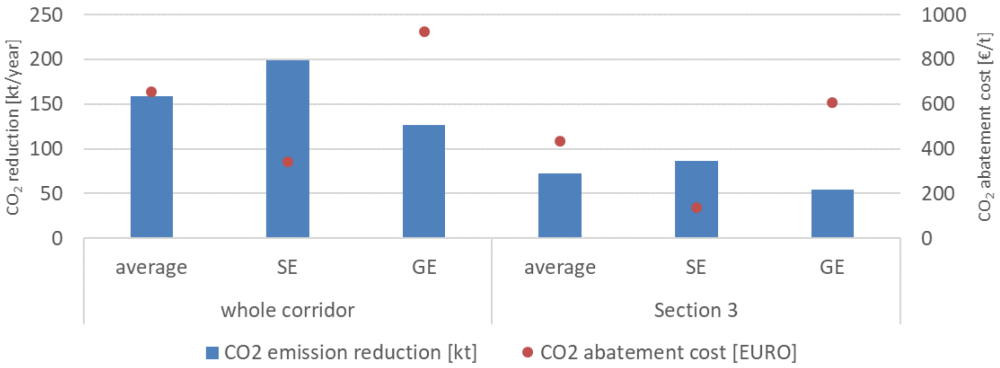


Figure 22: CO2 emission reduction potential per year and associated CO2 abatement cost for the Swedish-German ERS corridor

For "average" assumptions, the CO_2 abatement costs are relatively high for the entire corridor (about 600 €/tonne). However, based on Swedish electricity generation, which is quite low in CO_2 emissions, this figure is already well below 400 €/tonne. For sections with comparatively high specific traffic volumes of ERS-compatible traffic, the system costs per electrified vehicle kilometre are significantly lower (here section 3, running through Denmark, was selected as an example). If the Swedish electricity mix for supplying the ERS is applied here, the CO_2 abatement costs are around 140 €/tonne.

The values calculated for section 3 under Swedish conditions are also in the range of values calculated by Taljegard et al. [11]. The report estimates that for roads with an ADT between 1200 and 3100 vehicles (and all of them utilizing the ERS), CO_2 abatement cost of ERS technology will be in the range of 105-230 $€_{2016}$/ton CO_2. Taljegard et al. also show that the efforts to mitigate CO_2 through ERS on a larger road network yields a high CO_2 abatement "return" until approximately between 20 and 40 % of the road network is electrified: By electrifying 40 % of the Swedish E- and N-road network through ERS (assuming all vehicles driving on these roads were using the ERS), the total amount of emitted CO_2 from light- and heavy vehicle transportation in Sweden would decrease by 36 % and 55 % respectively. Electrifying the rest of the E- and N-road network (above the 40 % most trafficked roads) in turn, would only save a few more percentage points (45 % and 70 % for light- and heavy vehicles respectively) of the total national road emissions and would therefore not constitute an efficient CO_2 mitigation option.

The estimates calculated above make it clear that an ERS corridor, depending on its design, can certainly be an attractive measure for achieving CO_2 reductions in international freight transport already in a mid-term perspective. Since the suitability and thus also the cost balance of the Swedish-German corridor differs considerably between the sections, prioritization is advisable for optimization of CO_2 abatement costs. In addition, future developments of the political framework will play a decisive role:

- Electricity generation has the greatest influence on the actual CO_2 reduction. The additional expansion of renewable energy generation for an ERS corridor can significantly improve the ratio between investment costs in the ERS infrastructure and CO_2 reductions.

- The additional price of ERS vehicles is likely to depend to a large extent on whether these vehicles will pose an attractive means for manufacturers to meet their fleet emission targets.

The comparison of cases in Figure 22 has shown that the combination of parameters currently present in Sweden (cheap and clean electricity and expensive fossil fuels) may act as an effective driver and a necessary base for the implementation of ERS (or other green vehicle technologies) in coming years. Policies that affect these parameters (CO_2 tax, electricity tax, incentives for renewable power plants etc.) should be considered alongside plans to implement ERS to ensure the economic competitiveness and climate impact necessary for such systems to efficiently decarbonize the transportation sector.

6.3.3.2.3 Costs of ERS compared to other CO_2 mitigation technologies

ERS is not the only alternative propulsion technology with potential to lower CO_2 emissions within the transportation sector. However, it is clear that competing technologies are currently in the development phase as well, making cost estimates and comparisons tricky due to inherent uncertainties. So far, scientific studies in the area have tried to examine enclosed subsystems of the transportation system at large to give an indication of current and future cost estimations between different fuels, drivetrains and supporting infrastructure.

Boer et al. studied the production cost of long-haul trucks for different drivetrains with a diesel ICE as the base scenario [30]. They showcase that to produce long haul trucks for both catenary-conductive and inductive ERS today would cost approximately 170 000 $ compared to 80 000 $ for a diesel truck, while a fuel cell truck would cost above 400 000 $ to manufacture. A projection for 2030 is also done, where the diesel truck stays the same price, while both ERS compatible trucks are estimated to cost around 100 000 $ to produce, while the fuel cell vehicle is slightly more expensive at 120 000 $ per unit.

An overview of sources on total costs of ownership (TCO) for trucks with different propulsion technologies (see Figure 23) indicates that ERS are often estimated to have lower TCO compared to fuel cell trucks, battery electric trucks and diesel trucks using PtL. This comparison, however, does not take into account full CO_2 abatement costs and does not put them into perspective with potential CO_2 reductions.

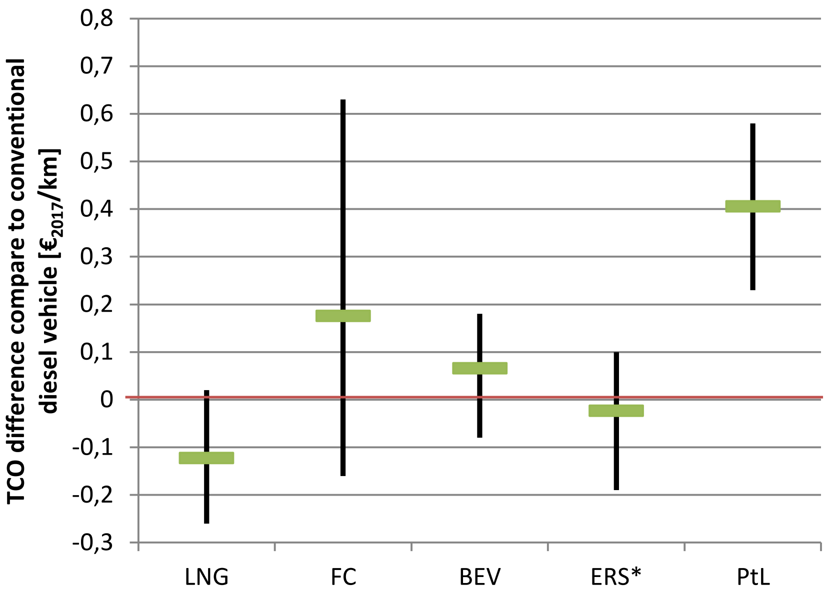


Figure 23: Differences in total cost of ownership (TCO) for different complementing drive systems and fuels compared to a fossil diesel vehicle 2020–2030 (*figures for catenary ERS). PtL means Power-to-Liquids i.e. electrofuels. The green horizontal bars show averages and the black vertical bars shows intervals between different studies. Infrastructure costs are not included. Source: ifeu.

Grahn et al. analysed the cost of different electricity-based fuels, drivetrains and infrastructure for light vehicles in Sweden [31]. The study shows that ERS can be a strong candidate from a cost perspective compared to electrofuels or large battery sizes for light vehicles at a total annual cost of approximately 2300 €/year for each vehicle, as can be seen in

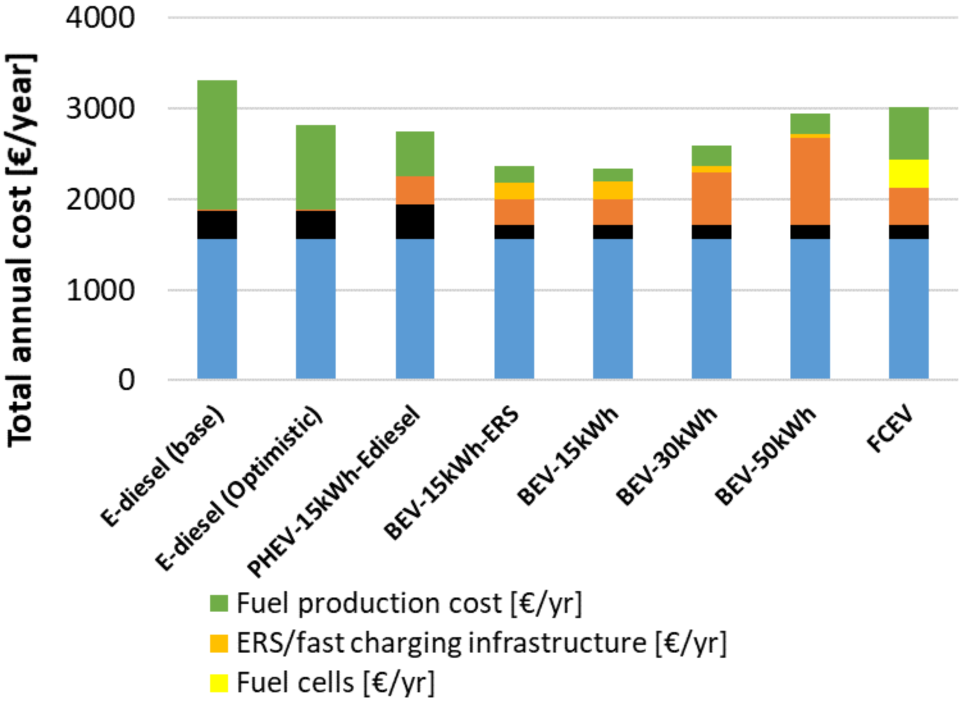


Figure 24. The main driver for this cost efficiency is that implementing ERS would have substantial cost benefits if the battery size can be reduced from 50 kWh down to 15 (or 30) kWh.

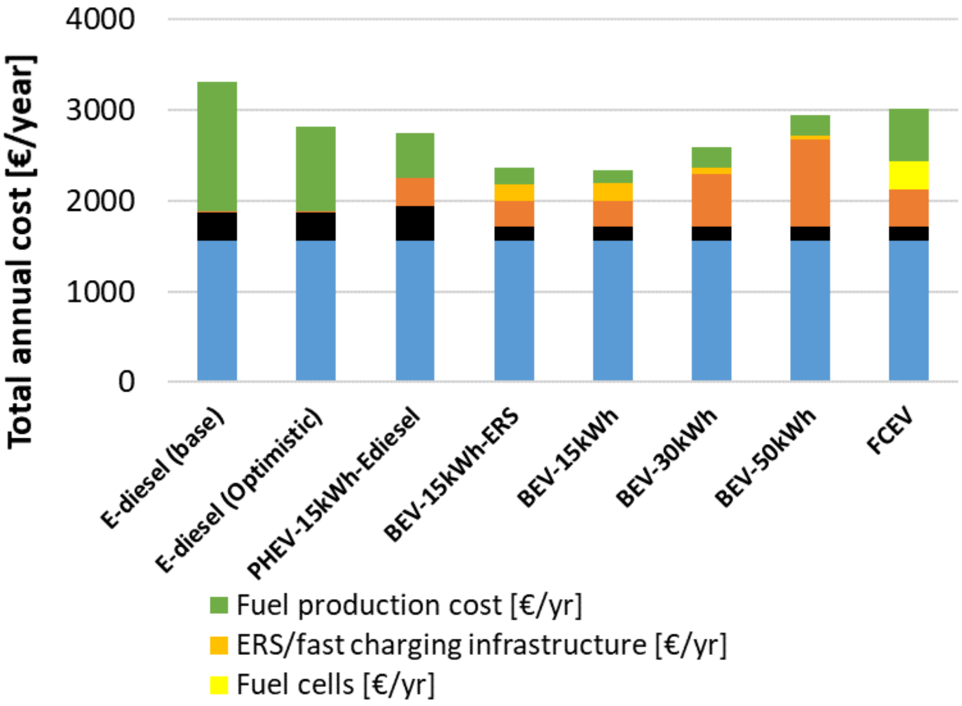
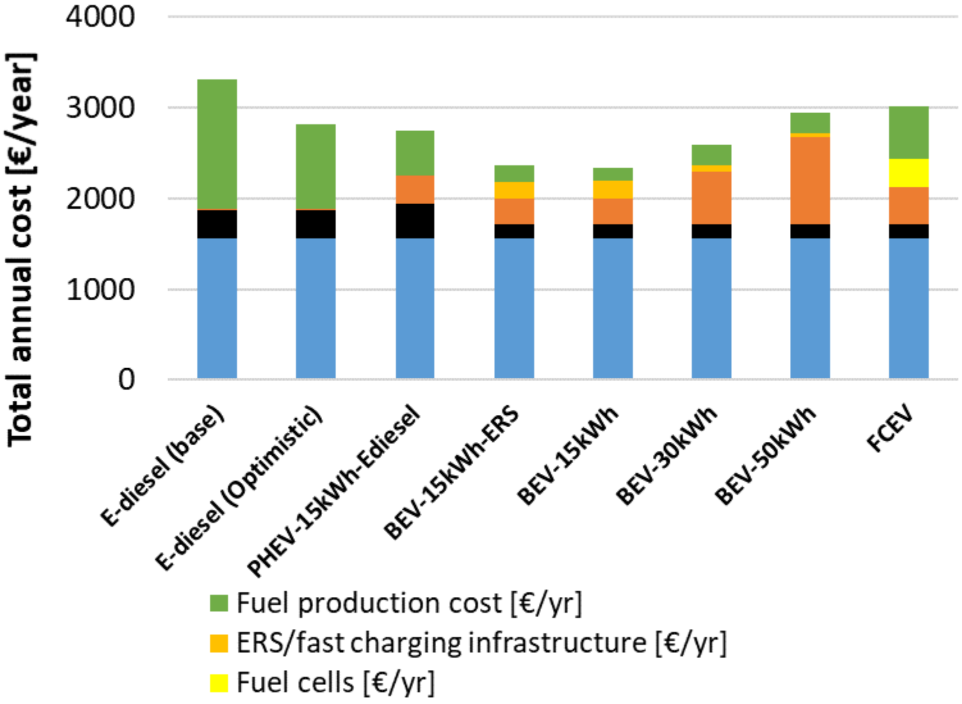


Figure 24: The total cost per year divided upon vehicle cost, fuel production and infrastructure cost for the different ways of using electricity for passenger cars assuming an annual driving range of 15 000 km and the base case cost estimates (E-diesel) from [31]

Furthermore, it is estimated that implementing ERS on a majority of the main road network in Sweden (along with a substantial utilization) will yield an ERS infrastructure cost of 0.03-0.07 €/vkm depending on road traffic volumes and the degree of utilization. In Figure 24, the ERS infrastructure cost amounts to 0.05 €/vkm.



In summary, the cost of mitigating CO_2 emissions through ERS (or other green vehicle propulsion technologies) depend on a number of different factors, such as necessary infrastructure, vehicle production cost, fuel production, storage options etc. Different technologies have different estimated costs for these factors, most of which are still under research. Currently, ERS is shown to have a lower energy cost compared to other propulsion technologies, which is a significant part of the total cost of transportation, especially for heavy vehicles. Simultaneously, there is a significant infrastructure cost that comes with implementing an ERS, the level of which is currently heavily debated, but range from a small share to the dominating part of the total driving cost of ERS. It is assumed that the cost of implementing ERS infrastructure will decrease as an ERS-network is being established due to economies of scale, thus will also the CO_2 abatement cost of ERS technology decrease the further it is expanded. Most current studies seem to place ERS in a favourable position for decarbonizing the transport sector compared to other options as seen from a variety of different perspectives.

6.3.3.3 Contribution to creating a substantial vehicle market

For manufacturers, it is very important what market size is expected for a product in the future. There are, for example, small batch productions that are tailored to the needs of a specific customer and for which only a relatively small quantity is expected from the first. This is what manufacturers base their production planning on. In this case, the customer usually has to accept a relatively high unit price.

If the expected production exceeds an order of magnitude of about 1000 units, the manufacturers set up the production facilities differently. The initial investments increase thereby, the production of an individual unit is connected however with clearly smaller expenditure and the production scales well with higher production quantities.

If a certain measure increases the sales of ERS vehicles in a predictable way, this can help manufacturers to design their production for larger volumes and thus exploit economies of scale. The construction of an ERS corridor can be such a measure. In broad terms, this means that around 12 000 vehicles can be considered for conversion to electric operation (purely electric or as diesel hybrids) (see Section 5.1.1). This corresponds to only about 11.4 % of the total vehicle population of this size class in the participating countries Sweden, Denmark and Germany. However, it is in the order of magnitude well above the above-mentioned threshold for volume production, even if several manufacturers would deliver this production.

It should be borne in mind that the above-mentioned number of vehicles represents an upper potential limit and, in particular, economic factors can reduce this potential. On the other hand, the isolated realisation of a Swedish-German ERS corridor is unlikely anyway, so that we can interpret the vehicle volumes mentioned here as a supplement to a demand driven primarily by national ERS expansion activities.

A very important function of a transnational ERS corridor from the manufacturer's point of view is to combine the respective national markets into one larger market. On the one hand, this facilitates the standardisation process (see Section 5.1.3) and thus helps to overcome usage barriers as well as market barriers. On the other hand, planning and thus investment security for vehicle manufacturers is improved if the individual national markets can be treated as a single large market.

6.3.3.4 Committing logistical and industrial stakeholders (carriers, shippers, OEMs)

It is of key importance to involve logistical and industrial stakeholders in these discussions, to find out more about their individual operations, their willingness to innovate and commitment to new technologies. A series of interviews with relevant stakeholders have therefore been conducted, to find out more about their current way of business, road activity between Germany and Sweden, and under what circumstances an ERS could eventually become attractive to them – specifically along the corridor.

Haulage companies that to some extent operate within or along the potential ERS corridor were addressed in both Germany, Sweden and Denmark. A good variety of market and customer segments were represented according to below specifics:

- **Number of employees:** 31— 1200 people
- **Number of vehicles (>12t):** 15 — 700 trucks
- **Client sectors:** Groceries, liquids, chemicals, wood & paper products, furniture, white goods, automotive parts etc.

The majority of these actors confirmed that transport along the corridor is responsible for more than 30 % of their total turnover, meaning that they are suitable representatives for recognizing possible benefits and challenges that an ERS corridor could mean to their future business. Some even informed that they have daily transport between the countries and that they presume continuous or even more freight transport in the future due to population growth and increased demand. However, few could tell whether they have dedicated HGVs that operate exclusively between Germany and Sweden, rather they constantly change routes, cover only parts of the corridor, or continue driving to other European countries after leaving the corridor. Consequently, flexibility is an issue where the carriers must be able to reach their loading and unloading sites via routes where ERS does not exist.

Contractual durations often range between 1-3 years while planning periods are short term, in most cases less than 2 weeks. Planned transports between Germany and Sweden are generally made via ferry connections and intermodal transports today. This is mainly due to the reason that a truck transport along the entire route is hardly compatible with the working time of the drivers. The ferry is often a good opportunity for drivers to have their daily rest. But, some transports are requested suddenly and require quick delivery where road transport sometimes become the preferred option. In ten years from now, the Fehmarn-Belt bridge is to be finished, which might offer an even more attractive case for road transports. One recurring argument on this topic is since road transport offer higher flexibility than the ferry, the bridge can increase that flexibility even more. However, pricing of the bridge and its effects on the ferry prices will play a large role in what the haulage companies decide to do once finished.

All haulage companies and carriers were asked what their criteria would be in order to buy ERS compatible vehicles assuming that an ERS corridor would exist. One argument that stands out as most important in total is economy – the technology has to pay off in order to justify the investment. The customer side must become more willing to pay for sustainable transport and regulatory measures should help making this a more viable option.

A conclusion from one of the actors is that they will probably not use an ERS corridor today to any significant extent unless there are autonomous ERS vehicles available. Drivers are difficult to find for them, thus the potential cost savings from utilizing an ERS corridor would still mean less flexibility than ferry or other intermodal transports regarding working times.

Other than economics, customer support and driver flexibility, the reliability and predictability of the infrastructure were repeatedly mentioned. It's important that weight, payload volumes or range does not become limiting factors, and that the haulage companies must be certain that an ERS network is large enough not to risk them having to drive detours in order to find charging. A suggestion from one of the actors is to initially get leasing offers for the ERS vehicles with short binding periods, meaning they could test and evaluate whether the technique is suitable for their operations before making larger investments.

6.3.4 Political Considerations

Besides technical challenges as well as potential environmental benefits and economic advantages, a transnational corridor should not be thought of as a stand-alone measure, but should also be viewed in the light of its political significance. The following discussion of political considerations is not restricted to the example of the Swedish-German corridor analysed above. Most considerations apply to transnational or also larger national roll-out projects. Nevertheless, the following aspects should be considered in a respective decision-making process.

6.3.4.1 Contribution to cross-border strategy for large scale implementation

It can be assumed that ERS has a higher chance of becoming a relevant factor in the concert of drive systems for heavy commercial vehicles if the actors at the international level agree on a coordinated approach for the introduction of the system. This concerns both technical concepts (i.e. technical standardisation) and the role that ERS should play in the context of decarbonisation efforts. A transnational ERS corridor can potentially contribute to such international agreements in various ways.

The implementation of an ERS corridor enabling transnational ERS traffic obviously requires **transnational technical standardisation**. Not all technical systems involved necessarily have to follow the same standards. However, it is at least necessary to standardize relevant interfaces. For example, it is conceivable that different variants of the power supply system are used on different sections of the corridor. However, the integration of the pantograph into the drive system and the billing modalities for the vehicle operators must be standardised in order to make the system sufficiently attractive for vehicle manufacturers and operators. The planning of a corridor is likely to give a boost to corresponding standardization activities.

Moreover, the analysis of potential electric mileages showed **considerable synergies** between the implementation of a Swedish-German corridor and national ERS network installation. It is likely that similar synergies might also result in other transnational projects. Thus, upon a decision to implement a corridor, it would make sense to align the national ERS expansion strategies. A corridor project could therefore possibly trigger strategic coordination between the participating countries. If the corridor planning process identifies certain national access routes as particularly relevant for traffic on the corridor, these may be considered accordingly in the prioritisation of national network development.

Finally, yet importantly, other countries are likely to take notice of a project of such an order of magnitude. Thus, a transnational ERS corridor can also contribute to raising awareness of ERS and its technical maturity in countries that are not involved in the corridor, encouraging these countries to define their position in terms of ERS policy. This can subsequently make it easier to integrate ERS into the strategic and regulatory EU framework. The following points are central to this:

- Link to EU roadmaps and targets in the transportation sector. This is first about building awareness in which cases ERS can contribute a great deal to reaching targets or is even inevitable for complying with the overarching targets. On that basis, it may make sense to formulate targets for ERS introduction itself.
- Link to relevant EU transport policy, e.g. the corridor could promote integration of ERS into important directives like AFID, CO_2 emission fleet targets for HGV, eurovignette directive.
- Link to EU transport network development, e.g. the ERS corridor could be explicitly defined as part of a European transport corridor initiative like the Scandria alliance.

6.3.4.2 Bridging the gap between demonstration and infrastructure scale-up

The transition between the implementation of pilot projects and the construction of a commercial ERS line is a major challenge in many respects. While in pilot projects the investment is limited and the focus is on gaining experience in real operation, on commercial ERS lines there is a clear expectation of success with regard to the goal of greenhouse gas reduction and other environmental, technical and economic criteria. In addition, a much larger number of stakeholders are generally involved.

An international corridor project could be an intermediate step between the two stages of system deployment. In terms of route length (424 km), the Swedish German corridor would definitely have a commercial scale. On the other hand, the participation of several countries raises a number of questions that need to be answered for the first time in such a project and give the project a strong pilot character on a higher level.

Due to its characteristics, a corridor project would in principle be eligible for EU research and development funding. For instance, the societal challenge “Smart, green and integrated transport” of EU’s Horizon 2020 work programme calls for building low carbon and climate resilient future by green vehicles and energy efficient propulsion for long distance trucks and coaches [32]. This call allows a budget of 55 million € in 2020. In addition, funding via the EU infrastructure budget would also be possible. The next EU long term budget (2021-2027) prioritises decarbonizing transport and encouraging alternative fuels [33]. Funding can be gained under the Connecting Europe facility programme.

Funding programme	Objectives of programme	Eligibility/Admissibility	Budget of call
Horizon 2020: Smart, green and integrated transport	The pillar Societal challenges of Horizon 2020 supports research and innovation targeting climate, environment, energy and transport. The work programme calls for smart, green and integrated transport	• Contents of project should meet the objective of the call • Proposals have to address the technical area of electro-hybrid drives	55 million €
Connecting Europe Facility	Aims to build, upgrade and improve European transport Infrastructure, promoting clean fuel and other innovative transport solutions.	• Projects on pre-identified corridor will be prioritized (Scandinavian - Mediterranean Corridor)	500 million €

For the Swedish German corridor, also integration into the Scandria project family [34] would be an option, which in turn would promote networking with partners in practice and bring such a project closer to economic realities. The Scandria project has a special geographic focus on the Scandinavia-Adriatic corridor and is also an important part of the Scandinavian-Mediterranean TEN-T corridor. The Scandria Alliance within this project provides support to transnational projects by focused co-operation across territorial borders, administrative levels and sectoral fields for coordinated funding, thereby integrating projects such as transnational ERS. The above-mentioned “hybrid character” of the project between pilot phase and system introduction could thus have an overall positive effect on the provision of funds and networking among stakeholders.

On the other hand, one can expect that a corridor project would be significantly easier (and faster) to implement if national ERS networks already exist or have at least been planned for. In addition, the relevant stakeholder groups could be addressed in a more targeted way if it is already clear from the national context which stakeholder groups are in principle open to ERS technology. Overall, this could make an argument for rather starting with a national implementation strategy, while a corridor project will be more likely to succeed at a later stage.

6.3.4.3 Showing political commitment

Numerous previous studies have concluded that a lack of commitment on the part of all actors involved represents a major obstacle to the implementation of ERS, e.g. Ref. [35]. Transport companies and truck manufacturers could interpret the successful planning and construction of an international ERS corridor as a sign that ERS are an important component of future decarbonisation strategies and thus enhance confidence in the system.

The planning of an international ERS corridor also addresses a frequent argument in the discussion about ERS, namely that ERS would only make sense in the case of an internationally coordinated system expansion. If politics now tackle an international ERS project of considerable scale, the message is that these concerns are taken seriously.

6.3.4.4 Lighthouse effect for ERS

At present, ERS as a technology has to struggle with very limited attention, even within the professional public dealing with electric drives in road traffic. In order to make ERS and its potential better known, lighthouse projects are indispensable. In the German and Swedish context, it has already been shown that ERS pilot projects attract a great deal of public attention. In addition, it has been proven that especially the permanent visibility of the technologies in everyday life can reduce fears of contact.

A corridor would expose a larger number of people to the technology and due to its international character might also attract greater media attention. In the case of an international ERS corridor, it can also be assumed that the overall level of attention will be even higher than in the case of a purely national project. A Swedish-German electrified corridor is therefore likely to have a considerable impact as a showcase project.

Additionally, if even the more complex international exercise is managed, then stakeholders could be more optimistic about national rollout. Moreover, since there are considerable synergies with national roll-out, the rationality of national rollout increases with successful international implementation.

On the other hand, decision-makers in international projects have repeatedly been criticised in the past for primarily targeting prestige. This is particularly the case when there is a suspicion that a national project would be more efficient with respect to its main goal. In the case of the Swedish-German corridor it can be argued that the truck traffic volumes and thus the achievable greenhouse gas reductions per electrified kilometre are lower than for some busy national sections in Germany and Sweden. Furthermore, the challenges of a transnational corridor can be assumed to be much higher than for a national rollout strategy, making delays or even failure of the project potentially more likely, which would then have negative effects on the perception of the technology.