Opportunities for electric road systems in road freight economics

A discussion paper from the CollERS2 project

Matts Andersson[1]*, Erik Johansson[1], Julius Jöhrens[2], Moritz Mottschall[3],

[1] WSP Sverige AB, Arenavägen 7, 121 88 Stockholm-Globen
[2] ifeu - Institute for Energy and Environmental Research Heidelberg, Wilckensstraße 3, 69120 Heidelberg
[3] Oeko-Institut Berlin, Borkumstraße 2, 13189 Berlin
* matts.andersson@wsp.com, julius.joehrens@ifeu.de

KEY TAKE AWAYS

- There are significant differences in total cost of ownership (TCO) between countries due to country-specific (energy) levies, subsidies, and toll systems. Countries aiming for a joint roll-out of electric road system (ERS) should aim to harmonize their framework conditions to ensure a predictable business case for ERS technology and to avoid subsidy-maximizing actors.

- Based on a TCO analysis of six countries, we find that battery electric vehicles (BEV) and ERS-BEV broadly have a cost advantage compared to diesel which is expected to stabilize around 2030, despite assumed fade-out of subsidies. Stationary charged BEVs will most likely be the most significant alternative for ERS vehicles, given a similar TCO. The most decisive factor will be applicable electricity prices (ERS vs. depot-charging vs. fast-charging) and infrastructure financing schemes for both ERS and static charging.

- National static charging plans are on a fairly advanced level today. Further development should take into consideration the synergies between static and dynamic charging, which could be done with the alternative fuels infrastructure regulation (AFIR), the revision of which will start in 2024.

- Most cost-benefit analyses of ERS are conducted on a national or subnational level, which makes sense if ERS investments are treated as national infrastructure investments. However, ERS is an environmental policy measure that can lead to large spill over effects, which suggests that a European level analysis would be more appropriate.

- The net social benefits of ERS are a function of other environmental policy measures. An analysis of environmental policies should be based on a similar “reference scenario” comparison (i.e., the baseline against which a policy scenario is compared). The reference scenario should assume that the other environmental policies are not implemented. As far as we know, no previous assessment of the social profitability of ERS has been made in this manner.

- The social benefits of an ERS also depend on how the fee users pay for charging is structured. A lower fee implies larger benefits to the users and greater emission reductions. If an external marginal cost user fee is chosen, it should be set so that the use of the transport system in general is optimized and adjusted for the marginal cost of public funds (which implies that the optimal tax is above the marginal cost).

Introduction

Despite rising electric vehicle sales, road transport is still dominated by the use of fossil fuels. Transport is responsible for about one quarter of global energy related greenhouse gas (GHG) emissions, with the largest share (about 72 %) coming from road transport (International Energy Agency, 2021). Fortunately, technologies enabling low carbon road transport are becoming commercially available or are under development, including battery electric vehicles (BEV), plug-in hybrid vehicles (PHEV), dynamic charging via electric road systems (ERS), fuel cell electric vehicles (FCEV), biofuels and synthetic renewable fuels. In the case of heavy-duty vehicles (HDV), these options are in different stages of technological maturity, commercialization, and development. The role of each option (or combinations of options) in a future sustainable road transport system is under debate (International Energy Agency, 2021; Kluschke, Gnann, Plötz, & Wietschel, 2019).

This discussion paper (DP) is the result of an international collaboration on ERS research called the CollERS2 project (https://electric-road-systems.eu/). The DPs are written in a joint context: DP1 covers technological aspects, DP2 covers standardisation and legal aspects, and DP3 (this paper) covers the use of ERS and economic aspects.

The first part of this paper addresses the socioeconomic aspects of an ERS. Since the benefits of ERS depend to a large extent on existing environmental policy, we describe relevant policy measures and context. This includes the regime for charging users, which is an important factor in determining socioeconomic profitability of ERS.

The second part of this paper deals with the specific strategic conditions for the use of ERS in different European countries. The road freight transport taking place in the respective country is characterised and, based on the economic and fiscal framework conditions, the economic efficiency of different propulsion technologies is compared from the operator's point of view in terms of TCO. In addition, the section looks at the countries' strategies for greenhouse gas reduction in the transport sector.

Methodological considerations for assessing socioeconomic impacts

Methodological approaches

Total Cost of Ownership (TCO) studies aim to determine the viability of different technologies from a user perspective. This is an important ingredient in a Cost-Benefit Analysis (CBA): if the technology is not viable for users, then it will not be implemented, and no benefits can accrue. A CBA aims to summarize all the impacts (benefits and costs) that may accrue to individuals in society. For infrastructure investments, the most important impacts include investment costs, maintenance costs, user benefits, and external effects (e.g., traffic accidents, pollution, CO_2 emissions) and effects for transport firms. The effects are, as far as possible, monetized. One of the most important non-monetized effects is intrusion (the effect of the infrastructure body on the landscape etc.).

One difference between CBA and TCO lies in the purpose. The purpose of a CBA is to determine which strategy (e.g., investments and policies) may be most socially beneficial. A TCO analysis, on the other hand, can tell you which technology will be chosen so that you can adjust the framework so that the beneficial technologies will be chosen. Another difference is that a CBA includes external effects such as accidents and pollution.

The decision of whether to undertake a TCO analysis or a CBA (that includes a TCO analysis) depends in part on how the infrastructure is financed in a country. If the infrastructure is financed mainly through user fees, a TCO analysis can help answer the questions about how the user will benefit and whether the user fees will cover investment and maintenance costs. If the infrastructure is financed with public funds, then it is important to capture all possible costs and benefits. A fundamental insight from fiscal federalism theory is that if there are few beneficiaries of something that many are financing, there will be excess demand of that something (Oates, 1972).

When benefits from investing in one region also leads to benefits in another region, it is referred to as a spillover. These spillovers can occur between regions within a country and between countries. A spillover benefit could occur, for example, when infrastructure is used by trucks from another country, which is the case with ERS systems that cross borders. Economics of scale also imply a spill over effect: the benefits of an ERS network increases when neighbouring countries also implement it. In countries where spillover benefits are handled through contracts between the affected regions (such in the USA), the demand for an objective tool for evaluation is less urgent (if a region thinks that the benefits are high, they will have to pay for it, hence they have no incentive to overstate benefits). When spillover benefits are managed cooperatively as with the Nordic countries (where decisions are made on a national level) there are regional incentives to overstate benefits. Hence, a strict and comparable tool such as CBA is needed. Despite the link between the financing method for ERS infrastructure and a reasonable evaluation method, there are complexities that make the choice of evaluation method challenging:

- Although there is usually one dominating method for infrastructure financing, all countries have exceptions. For example, regional co-financing of the national transport network is becoming more common in Sweden.
- No country relies on one single evaluate method. In Germany, for example, the infrastructure costs are sometimes assessed with respect to the CO_2 savings and CBA must be carried out for projects in the Federal Transport Infrastructure Plan.

The scientific literature covering CBA of investments in full ERS networks is fairly thin (see e.g., (Jang, 2018) for an overview). Most articles tend to analyze a single road stretch, while assuming a few given origins/destinations (Börjesson, Johansson, & Kågeson, 2021). Examples of articles analyzing networks are:

- Large-scale implementation of electric road systems: Associated costs and the impact on CO_2 emissions (Taljegard, Thorson, Odenberger, & Johnsson, 2020)
- Potential for reducing greenhouse gas emissions by electrifying freight transport on the Swedish E-road network (Jussila Hammes, 2020)
- The economics of electric roads (Börjesson, Johansson, & Kågeson, 2021).

There are two relevant CBAs that considered the connection to the decision making processes: Trafikverket (2021) in Sweden and Aronietis and Vanelslander (2021) in Belgium. German studies focus on TCO ((Wietschel, o.a., 2017), (Hacker, o.a., 2020), (Jöhrens, o.a., 2020)), which makes sense based on how the infrastructure is financed (see above). The TCO studies are accompanied by a calculation of infrastructure costs and, based on these two inputs, a calculation of repayment periods.

The CBAs by Trafikverket (2021) and Aronietis and Vanelslander (2021) are made on a national or subnational level, which makes sense if ERS investments are to be treated as national infrastructure investments. However, if ERS are seen as an environmental policy measure, there is a case for doing the analysis on a European level. The case for a European level analysis is further strengthened by the existence of large spill over benefits.

What can we say about the total benefits of ERS?

The main benefits of transport infrastructure accrue to users through better accessibility. Accessibility includes changes in transport time and transport costs. The time saving benefit of an ERS, compared to stationary charging, arises because recharging requires the driver to wait longer than a typical rest stop (e.g., when recharging takes time due to low power output or limited number of charging stations). Refuelling diesel vehicles has fewer limitations than stationary charging, in that respect. If we assume a similar carbon footprint for ERS vehicles and stationary charged battery vehicles, the main user benefit thus stems from reduced direct (operational) costs including transport time, fuel costs and vehicle costs.

If transport costs are reduced by installing an ERS, and outweigh other components of the TCO, then cost minimising firms will, according to theory, shift from diesel to electric drive. The marginal gains made by each vehicle can be multiplied by the number of vehicles. As such, roads with high average daily traffic (ADT) flows equates to many beneficiaries and hence large overall user benefits.

Another benefit of ERS is reduced CO_2 emissions, which is related to the level of ADT: a higher ADT that shifts to electric drive implies larger reductions in emissions. Eventually, however, this positive climate effect will drop over time as fossil diesel is phased out and replaced by low or zero emission fuels and zero emission vehicle (ZEV) technologies such as BEV. The calculated net benefits of an ERS therefore depends on scenario assumptions regarding the diesel vehicle fleet, year by year. This scenario will probably differ between countries.

In all, given that there are reductions in average operating costs, the relationship between the ADT and net benefits can be sketched as in figure 1 below. For simplicity, the figure assumes that all relevant costs and benefits are constant or proportional in relation to ADT, such as operations and maintenance costs (i.e., there is a fixed marginal cost per vehicle kilometre). At some level of ADT, as the figure indicates, there is a "breakeven point" (point A), where the benefits equal the costs.

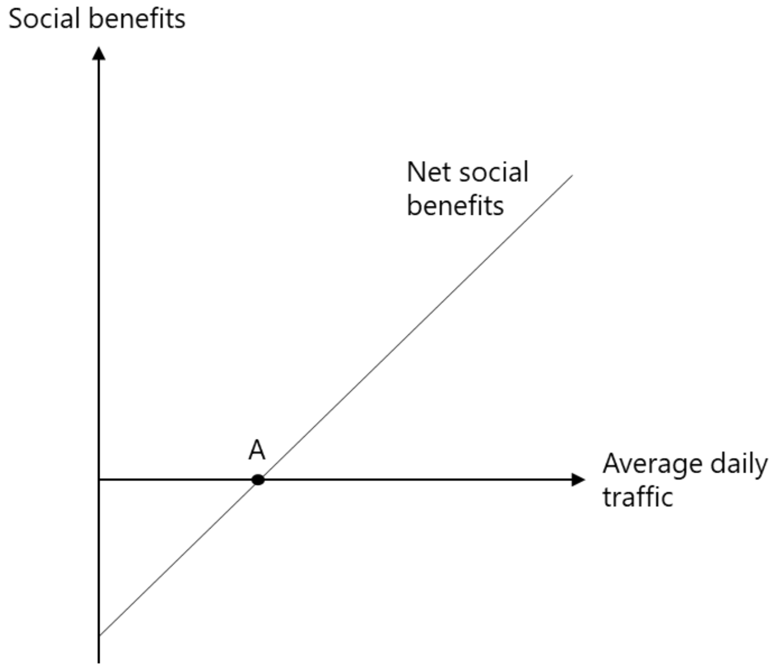

Figure 1. Sketched relationship between the use of infrastructure (average daily traffic or ADT) and net social benefits. The slope depends on the valuation of marginal benefit of reducing a unit of CO_2 and marginal savings for truck operations. The take-away is that the use of the infrastructure must be large enough to generate positive social benefits.

To the right of point A in Figure 1, the traffic is sufficiently large to generate positive net social benefits (the benefits to society exceeds to costs to society). The breakeven point is represented by the intercept on the horizontal axis (point A), i.e., fixed costs of the investment and the slope of the curve (the marginal net benefits). The slope is thus dependent on the valuation of marginal reductions in emissions and the reduced transport costs for carriers. This will most likely differ between projects and countries. Thus, to conduct a CBA on a European level requires a common valuation of carbon reduction (e.g., per kg CO_2). In all, the level of ADT determines the overall net social benefits.

The benefits of ERS depend on existing environmental policy measures

Since the benefits of ERS depend on the scenario for diesel usage, they indirectly depend on other environmental policies aiming to phase out fossil fuels. These policies may include, for example, biofuel quotas, taxes, or investments in other technologies. In the CBA conducted by Trafikverket in 2021, 40 percent of the total benefits of ERS disappear when climate goals are assumed to be reached through biofuel quotas (Trafikverket, 2021). Since existing environmental policies at that time included biofuel quotas to reach CO_2 targets in the transport sector in Sweden, it is logical to assume that they are implemented in an infrastructure CBA. However, one cannot draw conclusions about the efficiency of ERS as an environmental policy measure based on such evaluations. That would have required comparing CBAs of the policies assuming that the other policies are not implemented. In our opinion, there is a general lack of those types of studies in Europe.

The difference in CO_2 emissions between different ERS technologies is small compared to the difference between ERS and other technologies (Widegren, et al., 2021). Therefore, the most relevant choice is between ERS and other technologies, in this aspect. The main CO_2 difference is between direct use of electricity (either ERS or BEV) and anything else.

ERS benefits depend on user fees for charging

Before discussing the relationship between user fees for charging and user benefits, it is worth noting that fees may have multiple purposes: funding the infrastructure itself, external marginal cost pricing, or as a fiscal revenue for the general state budget. European countries have different traditions with respect to the purpose of a user fee. In Germany, there is a fee (toll) on HDVs on all federal trunk roads. Norway applies a fee on all vehicles on national roads and earmarks the money for infrastructure projects. Sweden does not normally rely on user fees to finance projects (the exception being three large bridges). In France, a concessionary system is used where private capital finances road infrastructure, and users pay a fee (toll).

The difference between fees based on marginal cost pricing and fees with the purpose of funding the infrastructure is as follows. The former aims to internalise the external marginal costs[1] imposed by the traffic, while the latter aims to cover investment costs and/or the operation and maintenance costs. While the former concerns the costs of the next marginal use of the infrastructure, the latter concern the average costs of (total construction costs divided by the number of users). Since external marginal cost pricing does not cover the financing for the infrastructure itself, funding must come from other sectors or markets in the economy. This financing implies taxes, which will cause distortionary effects on these sectors (referred to in the literature as "marginal cost of public funds"). Taking this into account, the socioeconomically optimal tax should be somewhat above the marginal cost.

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[1] "External costs" are costs that are not considered by the decisionmaker in his or her choice. Noise and emissions are commonly not considered by the individual road user, for example. These "externalities" can be "internalised" by a tax for example.

ERS user fees for charging vehicles

Looking at the transport sector and ERS specifically, the user fee should be set low enough to avoid under-utilisation, but at the same time high enough to include relevant costs and generate an efficient use of the infrastructure. Importantly, the impact of changing the user fee depends on its relative size compared to the other components of the TCO.

The demand curve can be illustrated by a straight downward sloping line as in Figure 2, with vehicle kilometres on the horizontal axis and user fee on the vertical axis. The curve captures how the number of driven kilometres on the ERS changes, as the user fee changes (per kilometre). In practice, the curve may or may not be linear, but the logic remains the same: The demand curve shifts outward or inward as the quantity demanded changes (given the same price level), which may occur for example when the fleet of ERS-trucks increases. The slope is determined by users' price sensitivity to the user fee. A vertical demand curve implies no sensitivity, whereas a flat curve implies infinite sensitivity.

Assuming a user fee equal to c_1 (Figure 2), the number of vehicle kilometres driven is vkm_1. The revenue for the ERS operator will be equal to vkm_1 (the use of the infrastructure) times c_1 (the revenue per vkm). The consumer surplus (or benefit) for the users is equal to the triangle above c_1 and under the demand curve in the top left corner. This represents the difference between a user's willingness to pay and what he/she actually pays.

A user fee of c* is assumed to be the efficient user fee (efficient in the sense that it yields the most efficient use of the infrastructure given the true social cost of usage). If the price is changed from c_1 to c*, then the revenue for the ERS operator changes to vkm* times c*. Whether this change yields an increase in revenue depends on the price elasticity: an elasticity greater than one implies that the vkm increases more in proportion to the change in c, and thus total revenue increases as a result of reducing the fee. A key take away is that knowledge of the market is important to set the right user fee and optimise revenue.

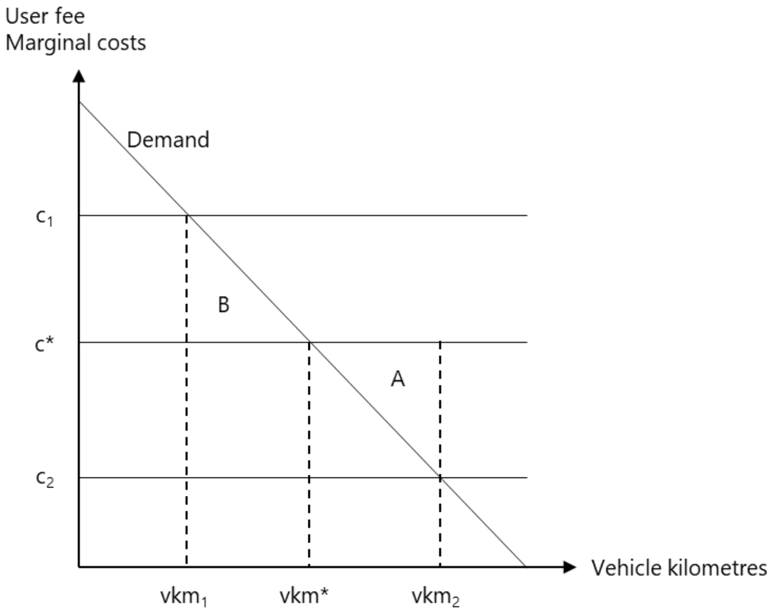

Figure 2. Simplified theoretical illustration of the demand in terms of vehicle kilometres with respect to the user fee. The illustration sketches the social costs associated with a user fee that is too low (c_1) and too high (c_2), compared to the user fee that results in the most efficient use of the ERS (c*). This logic holds regardless of whether the demand function is, or is not, linear.

At c* the consumer surplus is equal to the triangle above c* and under the demand curve, which is larger than at c_1. This triangle has three subareas. The previous consumer surplus is included on the top. The squared area below this triangle was previously part of the revenue of the operator but is now transferred to the consumer surplus. The triangle called B is the "new" benefit to the users that was not previously captured by the consumer surplus or by the revenue for the operator.

When the user fee is below the socially optimum level c* (as in c_2 in Figure 2), it yields a demand equal to vkm_2. At this level of c, the user pays less (c_2) than the true social cost of the usage (c*). This may occur, for example, where there is congestion on the road or when electricity demand is above capacity, but the user does not face these costs. In this case, there is a social benefit when the fee is increased to c*, as represented by the triangle A.

User fees based on external marginal cost pricing

With the marginal cost pricing principle, the price is used as a method of allocating resources to maximise social welfare, rather than maximising revenue for the infrastructure provider (Button, 1993). To generalise the above argument, if c is set below the optimal level, there will be overall welfare improvements by raising the fee. Similarly, if c is set above the optimal level, social welfare will improve if the fee is reduced. The aggregate welfare loss when c is above the optimal level is represented by area B in Figure 2.

How can the optimal level (c*) be found? First, the calculations require information on the external marginal costs of using the ERS and for the fuel system that would otherwise have been used (e.g., diesel or stationary battery charging). Note that we only include external marginal costs that are directly related to using the infrastructure, rather than costs related to annual wear and tear caused by e.g., weather. Second, the analyst needs to know the fees and taxes already paid for the use of these fuels. By calculating the difference between the external marginal cost and the tax per vkm for each fuel, one can obtain the non-internalised external marginal cost. Börjesson et al (2021) apply this method on Swedish data and calculate a fee for ERS usage equal to €0.094 and €0.096 per vkm for 40- and 60-tonne trucks, respectively.

The authors also discuss and calculate a profit maximising user fee (for the operator), which they estimate to be €0.128 and €0.178 for 40- och 60-tonne trucks, respectively. The impact on the CBA of adjusting the user fee to this level is that the profit for carriers drop, leading to less demand and hence lower CO_2 emission reductions from traffic. But since public funding is replaced by user fees, the tax burden imposed on other markets is eliminated (Börjesson, Johansson, & Kågeson, 2021).

The calculation presented in Table 1 follows Börjesson et al (2021) and relies on numbers from the Swedish official transport analysis guidelines (Trafikverket, 2020).[2] The necessary information can be summarised as in row 2 and 3 in Table 1 below where the numbers are in Euro, for the forecast year 2040.[3] The necessary information is: 1) taxes imposed on the consumption of each fuel, 2) external marginal costs caused by the traffic. The table summarises both diesel and BEV as alternative driveline to ERS. The example assumes a "tank-to-wheel" perspective that does not include external effects from e.g., battery production.

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[2] The exception is data on the wear and tear on the ERS infrastructure, which is proxied by the wear and tear of the electricity infrastructure for railways.

[3] 2040 is the forecast year in Swedish transport appraisals. "Forecast year" means that it is used as a base for the estimation of costs and benefits (see Trafikverket (2020) chapter 19 for an English summary of guidelines).

Table 1. An example of a calculation of the socially optimal user fee using numbers from the Swedish context and the forecast year 2040. Prices in Euro and price level 2022.

Term	ERS-BEV	Diesel	BEV
Tax per vkm, t	0.050	0.146	0.050
Unique external marginal costs per vkm, r	0.074	0.265*	0
Non-internalised unique external marginal cost per vkm, $e = r - t$	0.024	0.120	-0.050
Socially optimal user fee per vkm**, $c = e_{ERS-BEV} - e_{alternative}$			
Diesel as alternative	-0.095 (or 0 in practice)		
BEV as alternative	0.074		

**The external costs for diesel assume that the biofuel admixture is fixed at 5 % Fatty Acid Methyl Ester (FAME) and 18 % Hydrotreated Vegetable Oil (HVO).*

*** The equation considers the unique non-internalised negative external effects of ERS and the alternative fuels. See Börjesson et al* (2021) *for an application of this approach.*

Table 1 assumes that ERS-BEV and diesel have non-internalised external costs, whereas BEV does not. Although it is possible that there is a marginal wear and tear for BEV from using the charging stations, this is assumed to be insignificant. Since diesel has larger non-internalised costs than ERS-BEV, the estimated user fee is negative (in practice, equal to zero). By 2040, however, BEV is the most likely alternative "fuel" with which to compare ERS-BEV. Based on that comparison, the estimated user fee is €0.074.

Is it possible to have different pricing regimes in the same network?

The ideal ERS scenario, as discussed in DP2 (Andersson, et al., 2022), is that all users can drive through a sequence of EU member states with a uniform payment system. A uniform payment system means that the payment interface for the user is the same, but it does not necessarily mean that national road authorities must levy the same fee on all users.

On the contrary, it would be very likely that there will be different fees, even though all countries would apply the same charging principle. The infrastructure investment costs depend on local wages and material prices, as well as the expected utilisation of the ERS. Therefore, overall costs are expected to differ between countries. Marginal cost pricing will also depend on how each country values external costs associated with CO_2 emissions.[4]

The Eurovignette Directive regulates tolling and user fees on the trans-European road network. Member States may maintain user fees on certain sections of the network, but according to Article 5, the user fee shall not discriminate based on the nationality of the road user or the origin or destination of the transport (The European Parliament and of the Council, 2022). There is a theoretical risk associated with the possibility that countries with a lot of transit traffic might levy a higher user fee than what would be stipulated by the charging regimes described above.

Strategic reasoning regarding ERS in European countries

ERS have gained significant interest as a potential solution for reducing greenhouse gas emissions in the road freight transport sector. As a result, several EU member states have conducted feasibility

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[4] In the railway sector track access fees differ between states and between train type. Important costs on the railway sector to be reflected by the track access fees are wear and tear and congestion or scarcity costs (Nash, Crozet, Link, Nilsson, & Smith, 2018).

studies. However, the current state of ERS, the strategy for an effective rollout, and its role in achieving climate targets depends on several factors, including overarching climate strategies, existing transportation infrastructure, as well as country size and geographic location.

This chapter provides a brief country overview of the following: climate goals, the role of ERS, the current status of ERS, and other specific considerations for ERS implementation. Although the focus is on EU countries (Sweden, Germany, France, Austria, the Netherlands, Denmark, Belgium), other countries such as the United Kingdom, the United States, Canada, Norway and China are also showing interest in the technology. This chapter also presents an estimation of the full costs of the individual drive technology from a user's perspective. We focus on long-distance transport with articulated trucks as an example, which accounts for the largest share in terms of transport performance. We consider the following drive technologies as reference points: battery electric trucks with ERS (ERS-BEV) and without ERS (BEV), diesel hybrid vehicles with ERS capability (ERS-HEV), fuel-cell electric vehicles (FCEV) and standard diesel. For ERS vehicles, cost figures for catenary ERS technologies were applied, but vehicle-side costs are likely in the same order of magnitude for conductive rail and inductive ERS technology. The calculation of the full costs follows a simplified approach considering the purchase and financing costs, energy costs, fees (toll costs), and aggregated estimates for fixed and running costs.

Vehicle prices, including a prognosis to 2030 are based on (Jöhrens, o.a., 2022), which assumes there are no significant vehicle price differences between countries. Identical depreciation over time was assumed for all technologies. Energy costs, which often make up the largest cost category, are affected by large uncertainties and fluctuations. We use average electricity and diesel prices for the first half of 2022 in the individual countries as a basis. For electricity prices, this is likely to be an underestimate since the true costs when establishing new electricity contracts are often much higher than the average values. To address this, we also calculate the energy costs of diesel consumption based on the (lower) diesel prices from 2021 and show them separately in the illustrations. In view of the vast uncertainties regarding future energy markets, we assume the same energy prices for 2030 as for today, apart from hydrogen, where we assume declining costs towards 2030. Toll schemes are assumed "as is" for today, however, for 2030, we assume that the maximum CO_2 charge permitted by the Eurovignette directive (200 €/t) will be implemented by all EU countries and that there will be 75% reduction of the infrastructure fee for ZEV, which is the maximum permitted by the Eurovignette Directive. All assumptions for the calculations are compiled in Annex 1.

Sweden: pioneer of different ERS technologies with relatively low traffic volumes - in a coordinating role regarding ERS

Sweden is a pioneer in the development and deployment of ERS. As a component of its decarbonization plan, the Swedish government has established a target of reducing greenhouse gas emissions from the transportation sector by 70% by 2030 and attaining net zero emissions by 2045 (Naturvårdsverket, 2023). To meet these goals, Sweden is exploring the electrification of its transportation system. ERS has been identified as a potential complement to static charging infrastructure, as well as to hydrogen clusters, to accelerate the transition to electric and low-emission vehicles. In the short term, Sweden is focusing on the use of biofuels.

The Swedish government has established a "Commission for Electrification" to develop a deployment plan for ERS and static fast charging. Demonstrations of ERS on public roads have been conducted in Sweden since 2016 including overhead-catenary and ground-based conductive systems, as well as induction charging. The country has plans to implement its first permanent ERS by 2026 on a 21 km stretch of the E20 highway between Hallsberg and Örebro (Travikferket, 2022). One of Sweden's potential target networks that has been analysed for ERS implementation comprises 2,400 km, with a focus on priority routes in the southern region.

Expanding ERS in Sweden faces a challenge of low traffic volumes in certain regions, which could result in relatively low benefits per invested krona. However, a government inquiry suggests the introduction of a user fee to finance the ERS,[5] but no official decision has been made. Another challenge is the harsh winter conditions in central and northern Sweden, which may require additional measures to ensure the reliability and durability of ERS systems. Despite these challenges, Sweden is well positioned to play a coordinating role in the development and deployment of ERS in Europe.

In terms of total cost of ownership (TCO), there is a large gap in Sweden between (comparably) low electricity prices and high diesel prices (Figure 3). This makes electric driving attractive today and yields a TCO advantage of about 0.30 €/km for pure electric vehicles (both ERS and statically charged) over diesel vehicles (based on diesel prices in 2022). ERS-HEV, however, face about the same costs as diesel vehicles due to their diesel consumption (we assume vehicles operate 50% of the time in the diesel mode) and suffer from generally low purchase premiums for alternative truck technologies in Sweden. If the price of diesel were to decline, they would have a cost disadvantage. Yet, ERS-HEV would still be cheaper than hydrogen fuel-cell trucks that suffer from both high energy and high vehicle costs.

By 2030, we expect all alternative drive technologies to experience cost reductions, which means FCEV will reach cost parity with diesel technology. However, direct use of electricity in BEV or ERS-BEV is expected to yield a significant cost advantage of about 0.30 €/km. By then ERS-HEV might have a cost advantage over diesel vehicles, making ERS a potential exit strategy for pure combustion vehicles and making it a reasonable decision to provide an ERS network for long-haul truck traffic.

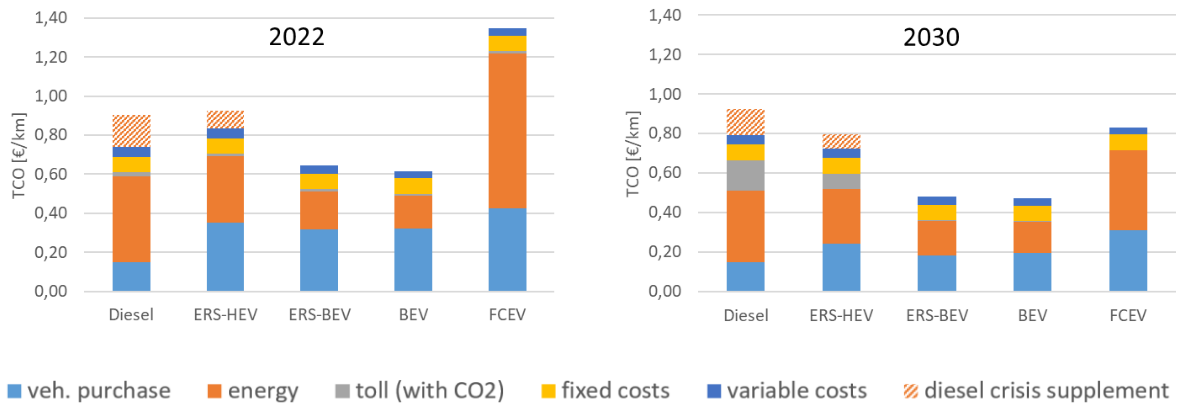

Figure 3. Total cost of ownership (TCO) for articulated long-haul trucks with different propulsion technologies in Sweden. Left: current situation; right: projection for 2030.

Germany: potential first mover with political and industrial drivers as well as high (inter)national traffic volume

Germany has ambitious goals for decarbonizing its transport sector, aiming for a 48% reduction in greenhouse gas emissions by 2030 (compared to 1990 levels), and climate neutrality by 2045 (Bundes-Klimaschutzgesetz, 2021). ERS are seen as a potential part of this strategy, with a goal of having one third of road freight travel via electric powertrains or e-fuels by 2030 (Bundesregierung, 2019). ERS, in

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[5] The report “Regulations for national electric roads” is in Swedish (SOU, 2021:73).

this case overhead catenary systems (OC-systems), are included in the national roadmap alongside BEV and FCEV, with a decision on the path forward expected around 2025 (BMDV B. f., 2020).

Currently, there are three test sections of ERS in Germany (each 5 km in length in both directions); a 7 km extension in Hessen is almost finished. In addition, two ERS "innovation corridors" have been announced but have not yet been approved (BMDV, 2021). Currently, there are approximately 20 OC-hybrid electric vehicles (OC-HEV) in operation, further, OC-BEV vehicles are included in plans for the near future. There is a high level of knowledge about ERS among active players in the industry, including the administration.

Potential innovation corridors for ERS in Hessen and Bavaria have been announced. Scientific recommendations for a target network cover about 4,000 km of existing highways, while also identifying initial suitable corridors (Florian Hacker J. J., 2020). These corridors would involve relatively short extensions to potential networks in neighbouring countries. Germany's high national and international traffic volumes, particularly on main transit routes between East and West Europe, make it an attractive location for ERS (Florian Hacker J. J., 2022). Freight hot spots include the Hamburg port and the Frankfurt area/airport, as well as the Duisburg port. Germany has a key industrial driver for ERS in the form of Siemens, which is actively involved in the development and implementation of the technology. Finally, the country’s highway infrastructure is coordinated centrally, which can facilitate ERS roll-out.

Due to the high purchase premiums for alternatively powered vehicles and extensive toll exemptions in Germany, electric vehicles (with and without ERS) and ERS hybrid vehicles have a cost advantage over diesel trucks. In the case of fuel cell trucks, however, the subsidies cannot yet fully compensate for the additional costs. The main obstacle for ramping up the market for ERS is the availability of vehicles and infrastructure, as well as the lacking confidence of the stakeholders in governmental framework conditions that would enable vehicle and infrastructure availability. The establishment of a large ERS pilot could send an important signal.

There is an expectation that by 2030, ERS and battery-electric trucks will have a cost advantage in Germany (even without subsidies), the cost advantage is expected to increase as these vehicles rely more and more on electricity. By that time fuel cell trucks could reach cost parity with diesel, but are not likely to be competitive with electric operation (with ERS or stationary charging).

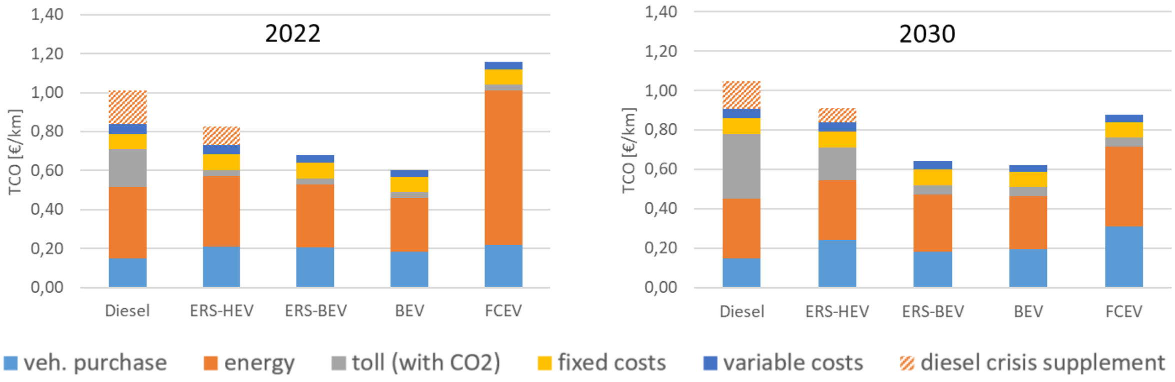

Figure 4. Total cost of ownership for articulated long-haul trucks with different propulsion technologies in Germany. Left: current situation; right: projection for 2030.

France: catching-up actor at high time pressure and with preference for ground-based ERS

The goal of France is climate neutrality by 2050 as part of its national low-carbon strategy (Stratégie Nationale Bas-Carbone (SNBC), 2022). Other objectives include minimizing energy and material consumption. The current strategy for transport in France focuses on the use of alternative fuels, with an update expected in the next two years. Actors in the industry are proposing the use of ERS for HDV, light-duty vehicles (LDV), and passenger cars. Stationary charging is seen as a supplementary option. There is currently no recommendation in the strategy for the use of hydrogen, e-fuels, or biofuels.

Several reports from July 2021 highlight the potential benefits of ERS in France. A call for projects was launched and closed in January 2023, but no project has been selected. However, hearings have taken place and a decision is expected in the first half of 2023. A ground-based demonstration project is the most probable option. France is also engaged in an exchange with Sweden and Germany on ERS. Finally, there is an ongoing push in 2023 at the EU level to select ERS technology to reach climate goals.

The evaluation of potential corridors for ERS in France focuses on the "TEN-T plus" network and the Paris-Rennes axis to Brittany, totalling approximately 4900 km in the first phase until 2030. An additional 4000 km is planned for phase 2 (2030-2035), with the goal of ensuring ERS access within a 125 km radius from every point in France. International connections to Germany and Belgium are included in the priority routes (Report, 2021).

There are several country-specific aspects to consider in the French roll-out of ERS. Private companies collect tolls on all vehicles today. These companies are seen as potential infrastructure builders or investors in ERS. France also has a big potential industrial player in the form of Alstom, which is actively involved in the development and implementation of a ground based conductive ERS. Finally, social acceptance is a big topic in France, with concerns about the visuals and costs of ERS (Expert Interviews, BOLD Projekt, 2022).

ERS are well placed (in terms of TCO) due to comparatively low electricity prices in France. Under current conditions, hybrid ERS vehicles could also compete with diesel trucks in terms of cost. Fuel cell vehicles are not economical even with subsidies. Operation of diesel trucks are expected to become more expensive in the future due to the CO_2 surcharge. Fuel cell trucks may be more attractive if hydrogen prices fall. Under the French framework conditions, however, a large cost gap is likely to remain between direct electricity use (with or without ERS) and the use of hydrogen in fuel cell trucks. The relative competitiveness of electric trucks that are exclusively stationary-charged, relative to ERS-capable trucks, will depend on future battery prices and the apportionment of infrastructure costs, which is not considered here.

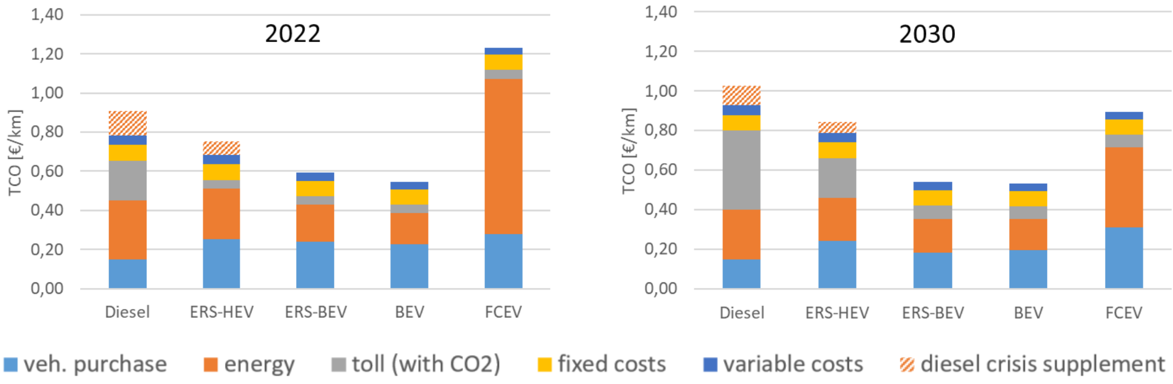

Figure 5. Total cost of ownership for articulated long-haul trucks with different propulsion technologies in France. Left: current situation; right: projection for 2030.

Austria: second mover with ambitious electrification targets but challenging topology for OC-ERS

Austria has ambitious goals for decarbonizing its transport sector, targeting climate neutrality by 2040. This includes a target for increasing the number of new registrations of emission-free LDVs and HDVs weighing less than 18 tons by 2030, and HDVs weighing more than 18 tons by 2035 (Federal Ministry for Climate Action, 2021). ERS are seen as a promising option in Austria, especially as a complement to stationary charging of BEVs.

There are no current plans for building a test track for ERS in Austria, but the country is considering an international perspective, given the rapid developments in neighbouring Germany.

A feasibility analysis of ERS in Austria has revealed significant limitations for the installation of overhead catenary systems on 12% of the TEN-T Core network. On 23% of the route candidates, expansion will not be feasible or reasonable, due to e.g., tunnels/green bridges or blocked lanes (Rohre, 2023). However, the remaining network can support an ERS system.

There are several country-specific aspects to consider in the roll-out of ERS in Austria. The country's highways are built, operated, and financed by Asfinag, a publicly owned stock corporation. Austria has a distance-based heavy-duty vehicle toll and is a landlocked country without an original equipment manufacturer (OEM). It also has high volumes of international traffic. Finally, the road topology in Austria presents challenges for the implementation of ERS (Expert Interviews, BOLD Projekt, 2022).

Austria levies a very high toll on diesel vehicles, which puts alternative drives in a better overall position compared to other countries. In particular, the use of ERS vehicles in the case of a corresponding infrastructure development could therefore bring considerable economic advantages, especially for long-distance transit traffic. This picture does not change fundamentally even with a view to 2030, as fuel cell trucks could only become a competitor economically in the case of very low hydrogen prices, far below the (already optimistic) assumptions taken here.

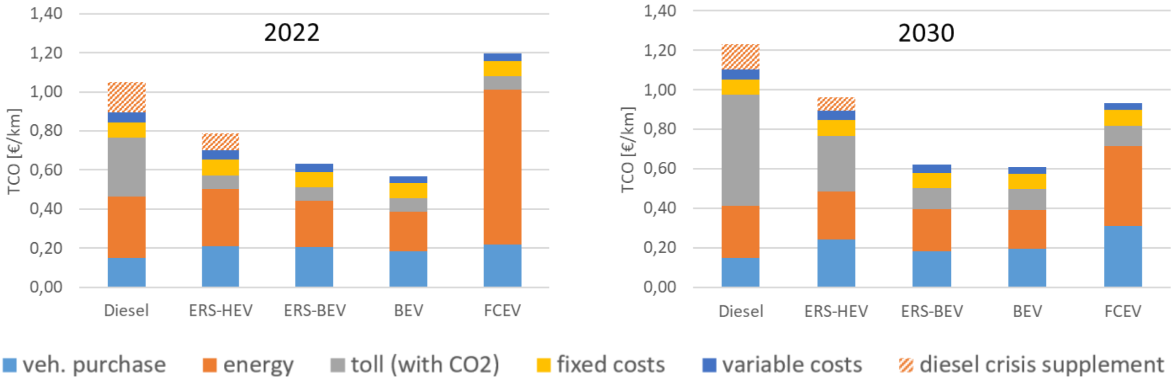

Figure 6. Total cost of ownership for articulated long-haul trucks with different propulsion technologies in Austria. Left: current situation; right: projection for 2030.

Netherlands: potential second mover with relatively short road network

The Netherlands has ambitious goals for decarbonizing the transport sector, as outlined in the 2019 Climate Agreement (Netherlands, 2019). This includes a target of a 49% reduction in greenhouse gas emissions by 2030 (compared to 1990 levels) and a 95% reduction by 2050.

There have been several studies on ERS in the Netherlands, with the latest study in May 2022 showing the cost effectiveness of ERS on main highways, if user uptake is high. However, no decision has been made on the implementation of ERS in the country, as there are still many uncertainties and international developments are crucial (Vliet, 2022).

Several potential corridors for ERS in the Netherlands have been evaluated, including: (1) the A2 Amsterdam-Eindhoven route (125 km); (2) an ERS network on main traffic routes (980 km); and (3) ERS on all motorways (2500 km) (Kees van Ommeren, 2022).

There are various country-specific factors to be addressed before deploying ERS in the Netherlands. The country has a relatively short road network, suggesting that static charging may be adequate for many trips. However, the Netherlands location is critical for cross-border freight transportation, with corridors for international freight traffic beginning or ending at freight hotspots such as the Rotterdam port and Amsterdam airport.

As things stand, hybrid ERS vehicles (assumption: 50 % operation on electricity) would be on par with diesel trucks in terms of cost. Fuel cell trucks are currently not competitive, even considering subsidies. In the long term, alternatively powered trucks can only be competitive with diesel under Dutch conditions if they are largely electrically powered. In view of the high proportion of long-distance international transport, this requires a corresponding infrastructure availability in neighbouring countries as well.

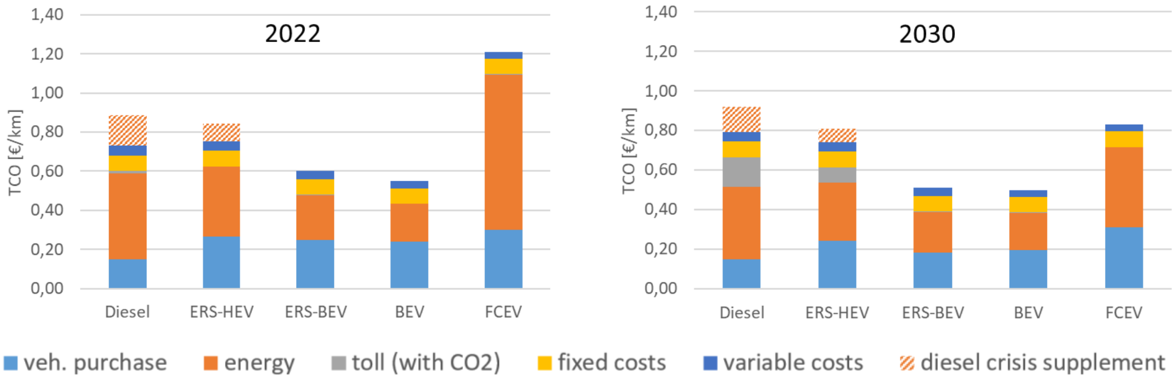

Figure 7. Total cost of ownership for articulated long-haul trucks with different propulsion technologies in the Netherlands. Left: current situation; right: projection for 2030.

Denmark: potential second mover with relatively short road network

Denmark enacted a climate law in 2019 that sets a target of reducing total emissions by 70 percent by 2030 but does not include sector-specific objectives. Denmark has a relatively short road network and is a potential second mover in the adoption of ERS. An academic study has shown the benefits of ERS, both for cars and LDVs. Different ERS technologies have been analysed in a recent study, with the ground-based conductive solution by Elonroad serving as the benchmark (Connolly, 2016). A new study on ERS has been commissioned for 2022 and will run until 2023.

Potential corridors for ERS in Denmark have been evaluated, with a recommended network of 1350 km, mostly on main routes. They recommendation includes a goal of ensuring access points within a maximum distance of 50 km from anywhere in the country.

A future ERS roll out in Denmark must consider the country's small geographic area and the high demand for international traffic in a peripheral location in Europe. Previous transport strategies have aimed to develop discrete roads, which means that a low visual impact is preferred.

The TCO of the various drive alternatives is, in principle, comparable to the Netherlands. However, the TCO advantage of electric drive is generally smaller in absolute terms due to relatively high electricity prices. In Denmark, too, ERS ultimately depends heavily on international transport and the corresponding conditions in the neighbouring countries since national road freight transport distances are too small to justify an ERS roll-out alone.

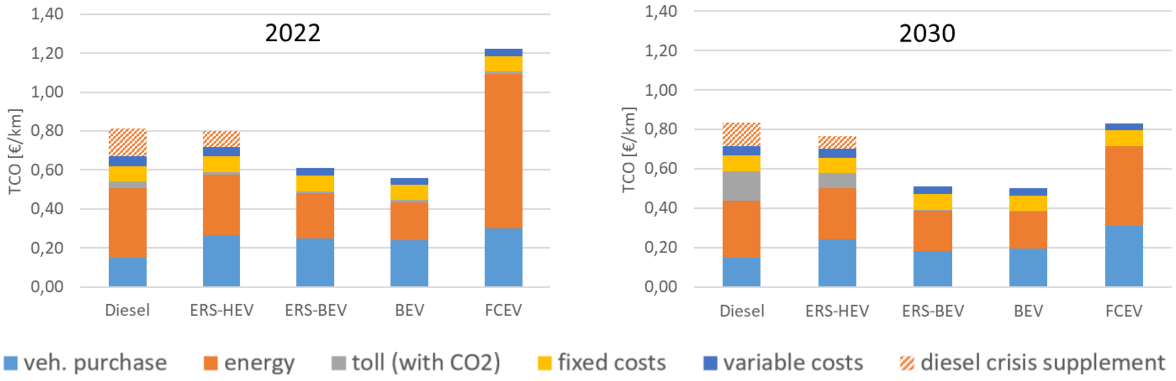

Figure 8. Total cost of ownership for articulated long-haul trucks with different propulsion technologies in Denmark. Left: current situation; right: projection for 2030.

Conclusions

CBA and methodological conclusions

Previous assessments of social profitability of ERS systems based on a CBA have taken a national or subnational level. This makes sense if ERS investments are to be treated as national infrastructure investments. However, ERS is an environmental policy measure that can lead to large spill over effects, which suggests that a European level analysis would be more appropriate. Further, the benefits of ERS depend on the existence other environmental policy measures. For example, a CBA by Trafikverket in 2021, showed that 40 percent of the total benefits of ERS disappear when Swedish climate goals are assumed to be reached through the biofuel quotas (Trafikverket, 2021), suggesting that the net social benefits of ERS is a function of concurrent policies. An analysis of environmental policies should be based on a similar “reference scenario” comparison (i.e., the baseline against which a policy scenario is compared) that assumes that the other environmental policies are not implemented. As far as we know, no previous assessment of the social profitability of ERS has been made in this manner.

The net social benefits of an ERS also depend on how the fee users pay for charging is structured. A lower fee implies larger benefits to the users and more emission reductions. If the user fee finances the roll-out, there will be smaller profits for users and lower emission reductions. On the other hand, there will be no need for external financing and hence no distortionary effects from taxes on other sectors in the economy. If an external marginal cost user fee is chosen, it should be set so that the use of the transport system in general is optimized and adjusted for the marginal cost of public funds of fiscal taxes (which implies that the optimal tax is above the marginal cost).

Conclusions from TCO analysis

There are significant TCO differences between countries due to country-specific (energy) levies, subsidies, and fee (toll) systems. Differences in energy prices are mostly structural (and most likely persistent), due in part to resource availability in different countries. Subsidies for purchasing alternative-drive vehicles play a central role today but will likely be phased out in the medium term. The fee (toll) systems currently employed by countries are heterogeneous, which has a significant effect on TCO analysis when considering diesel versus electric drive systems. However, the Eurovignette Directive will likely encourage harmonization towards 2030. How countries react will be decisive for the TCO balance of electric trucks compared to diesel trucks (and to hybrid trucks). Assuming a harmonized toll scheme in 2030 with a CO_2 price of 200 €/t, the CO_2 costs can be considered internalized in the TCO calculation. The remaining difference between TCO and CBA calculations will be the handling of infrastructure costs.

Today, both BEV and ERS-BEV have a broad TCO advantage compared to diesel, which means that market-uptake is hindered by other factors, such as infrastructure availability (obvious for ERS, but also relevant for stationary charging), vehicle availability, technological reliability, and confidence among operators. ERS-HEV only show a TCO advantage compared to diesel vehicles when grant a toll exemption. It remains to be seen if such vehicles can act as additional drivers for an ERS expansion. The TCO advantage of BEV and ERS-BEV is expected to stabilize towards 2030, despite assumed fade-out of subsidization. This also suggests that in comparison to a diesel reference, a CBA will most likely be positive for ERS since there is a big cost buffer that could be utilized for user fees. Due to their similar TCO, BEV trucks will most likely be the most important competitors for ERS trucks. There will be several decisive factors:

- Applicable electricity prices (ERS vs. depot-charging vs. fast-charging)
- Infrastructure financing schemes for ERS and static charging (user fees etc.)

- Traffic density of HDV on the national road network (more traffic → better pay-off for ERS)
- Share of international long-haul traffic on national road networks (where BEV is not expected to have a favorable TCO balance).

Countries aiming at a joint ERS roll-out should harmonize their framework conditions to enable a predictable business case for ERS technology. A plan for this should be communicated beforehand.

Conclusions with respect to countries' strategies

There is already considerable interest in ERS technology among the Central and Northern European member states. The intensity of ERS implementation varies greatly between countries, ranging from feasibility studies to initial pilot routes. Sweden and Germany are pioneers, while France has recently showed increased interest. The future success of the technology will depend on further promotion by pioneer countries, which is likely to encourage neighbouring countries to consider investment possibilities. Some key findings for the considered countries are summarized in Table 2.

Despite numerous national initiatives in recent years, there remains no coordinated European approach. The national plans for static charging are now on an advanced level and synergies between this technology and dynamic charging (viAn ERS) is likely to receive increased attention as the ERS technology is roll-out. But this requires that future plans involve strategies for both dynamic and static charging and specify possibilities for how these can work together. This could be done within the framework of the revision of the AFIR.

Table 2: Key findings in terms of ERS strategy and truck TCO in the considered countries.

Country	GHG reduction target or strategy	Status Quo of ERS strategy and roll-out	Total Cost of Ownership (TCO)
Sweden Relatively low traffic volumes	Transport sector: 70% reduction by 2030, net zero emissions by 2045 Midterm solutions include both biofuels and electrification	4 open-road demonstrations for different technologies; Permanent ERS planned for 2026: 21 km Possible target network: 2400 km	Significant cost advantage for BEV and ERS-BEV due to low electricity price.
Germany High national and international traffic volumes	Transport sector: 48% reduction by 2030, climate neutral by 2045 Road freight: 1/3 of mileage to rely on electric powertrains (or e-fuels)	OC-systems part of national roadmap along with BEV / FCEV Current test corridor includes 2 test sections of 5 km per direction and one section with 5 km in one direction and 12 km in the other direction (opening planned in April 2023). 2 ERS ”innovation corridors” announced Possible target network: ca. 4000 km	Heavy vehicle subsidization in the short run Comparably unfavorable energy prices for electrification ERS-HEV possible option for transition period

France Social acceptance can be affected by visual impacts and , costs	Climate neutrality by 2050 Current strategy still focused on low-carbon fuels, update expected in the next 2 years	Feasibility study completed, call for project, prefers ground based conductive ERS. Possible network of 4900 km by 2030, and 4000 km by 2035	Significant cost advantage for BEV and ERS-BEV due to low electricity prices.
Austria Challenging topography	Climate neutral by 2040 Increase in the number of new vehicle registrations that are emission-free: -LDV & HDV (<18t) in 2030 -HDV (>18t) in 2035	Feasibility analysis conducted for Catenary-ERS. Landlocked area with no domestic OEM of. High volume of transit traffic	High infrastructure fee (toll)→ big leverage from toll exemption for ZEV High and persistent cost advantage for electric drive
Netherlands Hot spots for international freight (e.g. Rotterdam port)	Transport sector: 49% reduction by 2030 (plus other ambitious goals)	3 Dutch studies on ERS Different corridor options evaluated, from 125 to 2500 km	Cost advantage for electric drive based on relative diesel and electricity prices
Denmark Short road network with international traffic	Overall reduction: 70% by 2030; Climate neutrality by 2050	Academic study on ERS for Trucks and LDV Recommended network: 1350 km	Comparably unfavorable TCO conditions for electric drive, but still TCO advantage.

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References

Andersson, M., Gather, M., Hartwig, M., Johansson, E., Lehmann, M., & Rodi, M. (2022). *Regulating Electric Road Systems in Europe - How can a deployment of ERS be facilitated? A discussion paper from the CollERS2 project.* CollERS2.

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

BMDV. (2021, 09 08). Pressemitteilung: BMVI bringt Innovationscluster für klimafreundliche Lkw-Antriebstechnologien auf den Weg. (B. f. BMDV, Ed.) Retrieved from https://www.klimafreundliche-nutzfahrzeuge.de/bmvd-bringt-innovationscluster-fuer-klimafreundliche-lkw-antriebstechnologien-auf-den-weg/

BMDV, B. f. (Ed.). (2020). Gesamtkonzept klimafreundliche Nutzfahrzeuge - Mit alternativen Antrieben auf dem Weg zur Nullemissionslogistik auf der Straße. Retrieved 10 5, 2021, from https://bmdv.bund.de/SharedDocs/DE/Publikationen/G/gesamtkonzept-klimafreundliche-nutzfahrzeuge.html

Boltze, M., Lehmann, M., Riegelruth, G., Sommer, H., & Wauri, D. (2021). *Elektrifizierung von Autobahnen für den Schwerverkehr.* Bonn: Kirschbaum.

Börjesson, M., Johansson, M., & Kågeson, P. (2021). The economics of electric roads. *Transportation Research Part C: Emerging Technologies, 125*.

Bundesregierung. (2019). Klimaschutzprogramm 2030 der Bundesregierung zur Umsetzung des Klimaschutzplans 2050. Retrieved 10 14, 2020, from https://www.bundesregierung.de/resource/blob/975226/1679914/e01d6bd855f09bf05cf7498e06d0a3ff/2019-10-09-klima-massnahmen-data.pdf?download=1

Button, K. (1993). *Transport economics* (2nd ed.). Cheltenham: Edward Elgar.

Expert Interviews, BOLD Projekt. (2022, 06 20).

Federal Ministry for Climate Action, E. E. (Ed.). (2021). Austria’s 2030 Mobility Master Plan - the new climate action framework for the transport sector: sustainable – resilient – digital. Vienna. Retrieved from https://www.bmk.gv.at/themen/mobilitaet/mobilitaetsmasterplan/mmp2030.html

Florian Hacker, J. J. (2020, 05 15). Wirtschaftlichkeit, Umweltwirkung und Ausbauszenarien von Oberleitungs-Lkw in Deutschland: Eine Synthese. (i. F. Öko-Institut, Ed.) Berlin, Heidelberg, Karlsruhe. Retrieved from https://publica-rest.fraunhofer.de/server/api/core/bitstreams/5a1d5449-8518-4114-98dc-284eaa617a35/content

Florian Hacker, J. J. (2022, 03). Mögliche Ausbauschritte für eine Oberleitungsinfrastruktur für den Straßengüterverkehr in Deutschland. . Hintergrundpapier im Rahmen des Projekts BOLD (Begleitforschung Oberlei-. (i. F. Öko-Institut, Ed.) Berlin, Heidelberg, Karlsruhe. Retrieved from https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cce/2022/BOLD_M%C3%B6gliche_Ausbauschritte_Oberleitungsinfrastruktur_in_Deutschland_2022.pdf

International Energy Agency. (2021). *Global EV Outlook 2021.* Paris: IEA.

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

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

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

Kluschke, P., Gnann, T., Plötz, P., & Wietschel, M. (2019). Market diffusion of alternative fuels and powertrains in heavy-. *Energy Reports, 5*, 1010-1024. doi:https://doi.org/10.1016/j.egyr.2019.07.017

Lesefassung des Bundes-Klimaschutzgesetzes 2021 mit markierten Änderungen zur Fassung von 2019. (2021). Von https://www.bmuv.de/fileadmin/Daten_BMU/Download_PDF/Klimaschutz/ksg_aendg_2021_3_bf.pdf abgerufen

Nash, C., Crozet, Y., Link, H., Nilsson, J.-E., & Smith, A. (2018). *Track access charges: reconciling conflicting objectives.* Centre on Regulation in Europe (CERRE).

Naturvårdsverket. (2023, 03 13). Retrieved from https://www.naturvardsverket.se/amnesomraden/klimatomstallningen/sveriges-klimatarbete/sveriges-klimatmal-och-klimatpolitiska-ramverk/

Netherlands, G. o. (Ed.). (2019). Climate Agreement. The Hague. Retrieved from https://www.klimaatakkoord.nl/binaries/klimaatakkoord/documenten/publicaties/2019/06/28/national-climate-agreement-the-netherlands/20190628+National+Climate+Agreement+The+Netherlands.pdf

Oates, W. E. (1972). *Fiscal Federalism.* New York: Harcourt Brace Jovanovic.

Report, W. (2021, 07). Decarbonizing road freight transport through ERS, issues and strategy.

Rohre, M. (2023, 02 15). EnergyRoads - ERS (pre-)feasibility study for Austria. *Presentation at the CollERS Symposium zu Electric Road Systems*. Berlin.

SOU. (2021:73). *Regler för statliga elvägar.* Retrieved from https://www.regeringen.se/rattsliga-dokument/statens-offentliga-utredningar/2021/09/sou-202173/

Stratégie Nationale Bas-Carbone (SNBC). (2022). Retrieved from https://www.ecologie.gouv.fr/strategie-nationale-bas-carbone-snbc

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

The European Parliament and of the Council. (2022, 03 24). *Directive 1999/62/EC of the European Parliament and of the Council of 17 June 1999 on the charging of vehicles for the use of road infrastructures.* Retrieved from EUR-Lex: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=LEGISSUM%3Al24045b

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

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

Travikferket. (2022, 03 22). CollERSII-Workshop: Exchange on international ERS projects .

Widegren, F., Helms, H., Hacker, F., Andersson, M., Gnann, T., Eriksson, M., & Plötz, P. (2021). *Ready to go? Technology Readiness and Life-cycle Emissions of Electric Road Systems - A discussion paper from the CollERS2 project.* https://electric-road-systems.eu.

Annex

Year 2022

	Unit	SE	DK	DE	NL	FR	AT	Notes
ZEV purchase premium	%	30%	60%	80%	60%	65%	80%	Public subsidization of price difference between a new conventional diesel truck and a new zero-emission truck. Values are based on public documents of the respective authority.
Diesel price (w/o VAT) - reference - crisis	€/Liter	1,38 1,89	1,16 1,61	1,19 1,72	1,35 1,84	1,06 1,45	1,05 1,54	Weekly average diesel price (without value added tax) from 11.01.2021 to 27.02.2022 (reference) and from 28.02.2022 to 19.06.2022 (crisis) respectively.[6] Source: Weekly Oil Bulletin
Hydrogen price (w/o VAT)	€/kg	10,8	10,8	10,8	10,8	10,8	10,8	assumption based on current prices at HRS from www.h2.live
Electricity price (w/o VAT)	€/kWh	0,11	0,16	0,15	0,13	0,12	0,14	Electricity prices from the first half of 2022 for consumer between 500 MWh and 2 000 MWh per year (without value added tax). Source: Eurostat
standard toll (diesel)	€/km	0,02	0,03	0,20	0,01	0,20	0,30	Values are based on public documents of the respective authority and include the CO2 charge.[7]
differentation of the infrastructure charge	%	100 %	100 %	0%	25%	25%	25%	percentage of infrastructure charge that has to be paid by zero-emission trucks compared to diesel trucks (excluding air and noice pollution charge)
fixed costs	€/km	0,08						Includes Vehicle tax, Inspection, Insurance and Maintenance. Source: Jöhrens et al. 2022
variable costs	€/km	0,04-0,05						Includes tires, lubricants, variable part of maintenance. Source: Jöhrens et al. 2022

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[6] CO_2 components of the price have been removed and put consistently to the toll. Mineral oil tax refund for France (0,157 €/Liter) is considered.

[7] For countries with a Eurovigniette flat tarif per vehicle, per-km values have been calculated based on an annual mileage of 100 000 km.

Year 2030

Same assumptions as for 2022, except:

- Vehicle cost degression according to Jöhrens et al. 2022
- no ZEV purchase premiums in 2030
- CO2 charge of 200 €/t consistently across countries (which is the maximum currently permitted by Eurovigniette directive)
- H2 price of 6,03 €/kg (in line with Repenning et al. 2021 for the case of H2 import and central distribution)
- 75 % reduction of infrastructure charge in toll for ZEV