

Electric Road System: Social Cost Benefit Analysis

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Samenvatting

Inleiding: Dit rapport beschrijft een vervolgstudie naar de maatschappelijke kosten en baten van de implementatie van een Electric Road System (ERS) voor vrachtwagens in Nederland. Eerdere studies lieten hiaten zien in de beoordeling van de baten of waren geografisch niet specifiek. Deze studie maakt deel uit van het internationale samenwerkingsproject E-CORE, dat de haalbaarheid en voordelen van ERS in heel Europa evalueert. De toepassing van ERS-technologie, waarbij zware batterij-elektrische voertuigen (BEV's) dynamisch kunnen opladen via bovenleidingen, wordt vergeleken met een scenario waarin alleen stationaire laadinfrastructuur beschikbaar is.

Het primaire doel van dit project is om de maatschappelijke impact, kosten en baten van de implementatie van ERS te begrijpen, specifiek voor twee afzonderlijke goederencorridors vanuit Rotterdam: richting Duitsland (Corridor 1) en richting België (Corridor 2). De studie beoogt te beoordelen of ERS kosten kan verlagen en efficiëntie kan verbeteren in de logistieke sector, vergeleken met het scenario met alleen stationair laden, waarbij dezelfde vermindering van directe broeikasgasemissies wordt bereikt. Een gevoeligheidsanalyse onderzoekt diverse factoren die de kosten-batenuitkomsten kunnen beïnvloeden, zoals bouwkosten, energieverbruik, batterijprijzen, batterijgroottes en het aantal O-BEV's (Overhead Battery Electric Vehicles) op een ERS-corridor.

Methodologie: De analyse volgt een systematisch proces zoals voorgeschreven voor maatschappelijke kosten-batenanalyses (MKBA) in Nederland:

- Definitie van het basisscenario (scenario 1: alleen stationair laden) en het projectalternatief (scenario 2: met ERS naast stationair laden).
- Ontwikkeling van de aannames en opzet voor de MKBA.
- Gegevensverzameling en modelontwikkeling.
- Interpretatie van resultaten en rapportage.

De belangrijkste potentiële voordelen van ERS, vergeleken met batterij-elektrische voertuigen die alleen stationair laden, liggen in operationele kostenbesparingen dankzij kleinere batterijen en het wegvallen van wachttijd voor het opladen. De belangrijkste kosten liggen in de investering, exploitatie en het onderhoud van ERS-infrastructuur: de bovenleidingen, netaansluitingen en de kosten van pantograafapparatuur om vrachtwagens met de bovenleiding te verbinden. De focus van de MKBA ligt op dit belangrijkste kosten-batenmechanisme.

Belangrijke aannames en beperkingen: In dit project is voortgebouwd op bestaande kennis, waarbij gegevens uit eerdere studies zijn gebruikt voor de maatschappelijke kosten-batenanalyse. In bepaalde onderdelen is recentere data verwerkt om de nauwkeurigheid te verbeteren. Vanwege een relatief beperkt budget en een strakke planning is de aanpak van sommige onderdelen beperkt gehouden. Hoewel de richtlijnen voor MKBA zoveel mogelijk zijn gevolgd, lag de nadruk in deze studie op financiële en in geld uit te drukken effecten. Een diepere analyse van enkele moeilijk te kwantificeren effecten en complexe marktmechanismen rond elektrificatie van vrachtvervoer is niet uitgevoerd.

Met dit in gedachten gelden de volgende overwegingen, aannames en beperkingen voor de analyse:

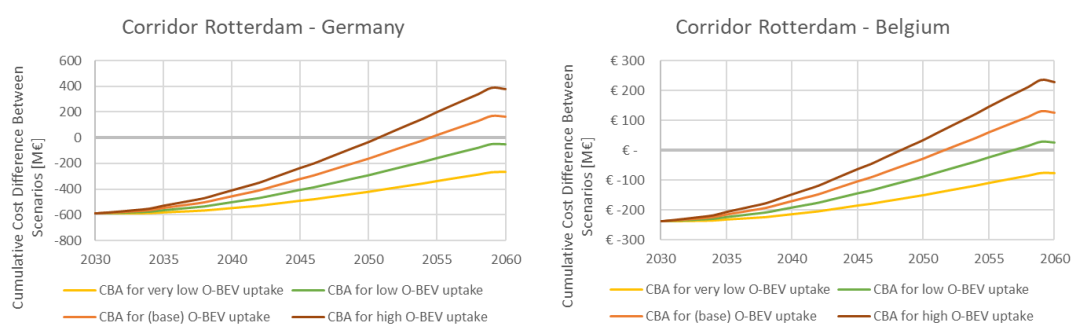
- **Batterijkosten:**
 - De verschillen in voertuigkosten tussen batterij-elektrische vrachtwagens (BEV) en ERS-vrachtwagens (O-BEV) worden sterk beïnvloed door batterijprijzen (€/kWh) en verschillen in batterijgrootte. Er wordt verwacht dat O-BEV's kleinere batterijen zullen gebruiken, maar in hoeverre dit in de praktijk het geval zal zijn is onbekend. Een meer gedetailleerde analyse van herkomst en bestemmingen, evenals van variaties in het dagelijkse gebruik van vrachtwagens op de corridor, is nodig om het potentieel voor batterijreductie door gebruik van ERS beter in te schatten. Dit was echter niet mogelijk met de beschikbare data voor dit project. In deze studie gaan we uit van 700 kWh batterijen voor BEV's en 150 kWh batterijen voor O-BEV's.
 - Bovendien zijn de batterijprijzen in toekomstige jaren onzeker. Schattingen variëren tussen de 40 en 120 €/kWh in de periode 2030-2050, wat aanzienlijke gevolgen heeft voor de businesscase. Voor de gemiddelde schatting in onze berekening hebben we de meest recente studie gebruikt (Link et al., 2024), die rekening houdt met meerdere eerdere studies. Er is een gevoeligheidsanalyse uitgevoerd met betrekking tot variaties in de ontwikkeling van batterijprijzen en mogelijke reductie van batterijgrootte.
- **Infrastructuurkosten:** Op basis van meerdere publicaties is een plausibele kostenrange voor ERS-infrastructuur vastgesteld. Deze kosten zijn echter onzeker en kunnen variëren tussen 1 miljoen €/km en 4 miljoen €/km (voor twee rijrichtingen). Als gemiddelde waarde voor onze berekening hebben we een vaste prijs aangehouden, zoals berekend in een eerdere studie van Movares (2020). Ook voor deze parameter is een gevoeligheidsanalyse uitgevoerd.
- **De analyse is gevoelig voor zowel het aantal vrachtwagens op de corridor als het scenario voor de adoptie van BEV's en O-BEV's.** De vraag naar ERS is echter niet gemodelleerd op basis van prijselasticiteit of operationele profielen van voertuigen op de corridor. In plaats daarvan is een vast percentage van het verwachte aantal BEV's aangenomen, zonder rekening te houden met prijsgevoeligheid of gebruikspatronen die de vraag naar ERS nauwkeuriger zouden kunnen voorspellen.
- **Elektriciteitskosten:** Publieke en private laadlocaties hebben verschillende energieprijzen. Het is onzeker in hoeverre elektriciteitsprijzen gedurende de dag en nacht fluctueren en welk effect dit heeft op zowel dynamische als stationaire laadtarieven. De effecten van elektriciteitsprijzen en dag/nacht-variaties zijn niet onderzocht in deze studie. Nachtelijk laden kan leiden tot lager gebruik van hernieuwbare energie, wat hogere prijzen tot gevolg kan hebben. In deze studie wordt uitgegaan van een vaste netprijs voor zowel ERS- als depotladen, en een vaste stroomprijs voor gebruikers van ERS, ongeacht de benutting.
- **Tijdeffekten:** ERS elimineert de noodzaak om te stoppen voor het opladen, en voorkomt zo potentiële wachttijd die gepaard gaat met stationair laden. Dit voordeel is verwerkt in de berekeningen via de waarde van tijd (o.a. uurloon chauffeur).
- **Depotladen:** De noodzaak om infrastructuur voor nachtelijk laden aan te leggen is beschouwd als een extra kostenpost voor logistieke bedrijven. Dit omvat de investering die nodig is om nachtelijk laden voor voertuigen mogelijk te maken. De ontwikkeling van publieke laadinfrastructuur en de potentiële effecten van ERS op de beschikbaarheid van publieke laadmogelijkheden zijn niet opgenomen in deze analyse.

Er wordt van uitgegaan dat een enkele corridor geen significante impact heeft op de uitrol van publieke laadpunten, aangezien deze laadpunten andere gebruikers blijven bedienen die geen gebruik kunnen maken van ERS.

- Gewichtseffecten: Een effect dat niet is meegenomen betreft het gewichtsvoordeel van O-BEV's ten opzichte van BEV's. Volgens een recente studie van de Universiteit van Cambridge (David Cebon, University of Cambridge, 2024) kan het nuttige laadvermogen van elektrische vrachtwagens door grote batterijen met wel 25% afnemen. Deze reductie kan leiden tot hogere vervoerskosten bij gewicht gelimiteerd vervoer. ERS kan helpen dit probleem te beperken door de noodzaak voor grote batterijen te verminderen en zo het laadvermogen te behouden.
- Aanvullende, relatief kleine effecten worden verwacht van bijvoorbeeld visuele verstoring door de bovenleidingen op snelwegen (een maatschappelijke kostenpost), maar deze zijn niet meegenomen.
- Strategische argumenten vóór ERS zijn onder andere het potentieel voor minder afhankelijkheid van kritieke grondstoffen voor batterijen, vermindering van netcongestie en een snellere uitrol van voldoende laadinfrastructuur. Deze zijn niet opgenomen in de kwantitatieve analyse. Ook mogelijke milieuwinsten, indien ERS de energietransitie voor vrachtvervoer kan versnellen, zijn niet geëvalueerd.

Resultaten:

De berekeningen geven aan dat het gebruik van O-BEV's onder bepaalde voorwaarden een financieel gunstigere oplossing voor de samenleving kan zijn dan een scenario met uitsluitend BEV's. Op basis van onze aannames worden de initiële investeringen voor beide corridors, vanuit de Haven van Rotterdam naar Duitsland (Corridor 1) en naar België (Corridor 2), geschat op respectievelijk €590 miljoen voor 180 km ERS en €239 miljoen voor 72 km ERS. De Netto Contante Waarde (NCW), bij een discontovoet van 3% over een periode van 30 jaar, bedraagt €6,51 miljard voor Scenario 1 (Referentiescenario) en €6,34 miljard voor Scenario 2 (ERS-alternatief) op Corridor 1. Voor Corridor 2 is de NCW €3,11 miljard voor Scenario 1 en €2,98 miljard voor Scenario 2. Figuur 0.1 laat zien dat, afhankelijk van de adoptie van O-BEV's op de corridors, het voordelig kan zijn om ERS-infrastructuur aan te leggen.



Figuur 0.1: De maatschappelijke MKBA-uitkomst toont het verschil in cumulatieve NCW van de kosten voor het BEV-only scenario en het O-BEV-scenario voor Corridor 1 (Rotterdam-Duitsland) en Corridor 2 (Rotterdam-België) met 4 verschillende O-BEV adoptiescenario's (Zeer laag = 50% van de adoptie in het basisscenario, Laag = 75%, Basisscenario, en Hoog = 125%).

Tabel 0.1 en Tabel 0.2 tonen twee belangrijke factoren die de uiteindelijke MKBA-uitkomst beïnvloeden: variaties in de ontwikkeling van batterijprijzen en in de kosten van ERS-infrastructuur per kilometer.

Tabel 0.1: Impact van vijf verschillende ontwikkelingen in batterijprijzen en ERS-infrastructuurkosten op de maatschappelijke kosten-batenanalyse (het verschil in NCW van de kosten tussen het BEV-only scenario en het O-BEV-scenario) voor de ERS-corridor van Rotterdam naar Duitsland. De batterijprijs scenario's zijn gerangschikt van laag naar hoog. De gemiddelde aanname voor batterijprijzen en infrastructuurkosten is onderstreept om het referentiepunt in de analyse te markeren.

Corridor 1		ERS infrastructure cost per km in both directions [M€/km]									
NPV for scenario difference [M€]		1.00	1.50	2.00	2.50	3.00	<u>3.28</u>	3.50	4.00	4.50	5.00
Battery price	Mauler et al. (2021)	476	371	265	159	53	-6	-53	-158	-264	-370
	Near Market	506	401	295	189	83	25	-23	-128	-234	-340
	<u>Average All (Base)</u>	648	542	437	331	225	<u>166</u>	119	14	-92	-198
	Scientific	670	564	458	352	247	188	141	35	-71	-177
	Other	713	607	501	395	290	231	184	78	-28	-134

Tabel 0.2 : Impact van vijf verschillende ontwikkelingen in batterijprijzen en ERS-infrastructuurkosten op de maatschappelijke kosten-batenanalyse (het verschil in NCW van de kosten tussen het BEV-only scenario en het O-BEV-scenario) voor de ERS-corridor van Rotterdam naar België. De batterijprijs scenario's zijn gerangschikt van laag naar hoog. De gemiddelde aanname voor batterijprijzen en infrastructuurkosten is onderstreept om het referentiepunt in de analyse te markeren.

Corridor 2		ERS infrastructure cost per km in both directions [M€/km]									
NPV for scenario difference [M€]		1.00	1.50	2.00	2.50	3.00	<u>3.28</u>	3.50	4.00	4.50	5.00
Battery price	Mauler et al. (2021)	236	194	151	109	67	43	24	-18	-60	-103
	Near Market	251	209	166	124	82	58	39	-3	-45	-88
	<u>Average All (Base)</u>	322	280	237	195	153	<u>129</u>	110	68	26	-17
	Scientific	333	290	248	206	163	140	121	79	36	-6
	Other	354	312	270	227	185	161	143	100	58	16

Analyse en conclusie: Vanuit maatschappelijk perspectief kan kostengelijkheid worden bereikt onder gunstige omstandigheden. De corridor van Rotterdam naar Duitsland presteert beter dan die naar België, omdat er op de eerste meer vrachtverkeer wordt verwacht (zie Hoofdstuk 4). Een gevoeligheidsanalyse werd uitgevoerd voor de belangrijkste onzekerheden. Het BEV-only scenario is gunstiger in scenario's met lage batterijprijzen en hoge ERS-investeringskosten, zoals blijkt uit Tabel 0.1 en 0.2. Het O-BEV-scenario is gunstiger wanneer de batterijprijzen hoog blijven of de ERS-kosten laag zijn.

Voor de kosten-batenanalyse van het bedrijfsleven (vlootbeheerders) is een discontovoet van 9,5% gebruikt. Voor de ERS-operator, beschouwd als een publieke investering, is een discontovoet van 3% toegepast.

Het resultaat van de MKBA voor de ERS-operator is negatief onder onze aanname van elektriciteitskosten voor gebruikers. Om een rendabele businesscase mogelijk te maken, moet de energieprijz voor eindgebruikers op de ERS boven de €1 per kWh liggen, zoals te zien is in Tabel 0.3.

Tabel 0.3: Netto contante waarde van de totale kosten en opbrengsten voor de openbare ERS-exploitant over een operationele periode van 30 jaar, voor verschillende waarden van de elektriciteitsprijs die aan de eindgebruikers in rekening wordt gebracht.

ERS laadkosten [€/kWh]	NPV Corridor 1 [M€]	NPV Corridor 2 [M€]
0.2	-695	-285
0.3	-624	-251
0.4	-552	-217
0.5	-481	-183
0.6	-409	-148
0.7	-337	-114
0.8	-266	-80
0.9	-194	-46
1.0	-122	-12
1.1	-51	22
1.2	21	56

De business case voor eindgebruikers wordt weergegeven in tabel 0.4, als functie van de prijs voor het opladen van elektriciteit uit het ERS. Voor alle andere inputparameters (bv. kostenontwikkeling van de batterij) worden gemiddelde waarden gebruikt. Voor elektriciteitsprijzen op het ERS lager dan 0,7 euro per kWh is er een positieve business case voor investeringen in O-BEV's en het gebruik van het ERS. Als de kosten voor het opladen op het ERS meer dan 0,7 euro per kWh bedragen, verdwijnt de financiële prikkel voor wagenparkbeheerders om het ERS te gebruiken, wat betekent dat de business case voor het gebruik van het ERS negatief wordt. In dat geval wordt het kostenvoordeel van de aanschaf van goedkopere trucks (door de kleinere batterij) ruimschoots tenietgedaan door de energiekosten tijdens het gebruik.

Tabel 0.4: Het effect van de elektriciteitsprijs voor het opladen op een ERS op de NCW van de kosten voor wagenparkbeheerders over een periode van 30 jaar van exploitatie aan het ERS

ERS laadkosten [€/kWh]	NPV Corridor 1 [M€]	NPV Corridor 2 [M€]
0.2	370	176
0.3	298	142
0.4	226	108
0.5	155	74
0.6	83	39
0.7	11	5
0.8	-60	-29
0.9	-132	-63
1.0	-204	-97
1.1	-275	-131
1.2	-347	-165

Conclusie en aanbevelingen: Deze studie onderzoekt de potentiële voordelen van het integreren van een ERS-corridor binnen het landschap van batterij-elektrisch vrachtvervoer op twee routes vanuit de haven van Rotterdam: richting Duitsland en richting België. De bevindingen tonen aan dat, onder gunstige omstandigheden, investeringen in ERS maatschappelijk rendabel kunnen zijn ten opzichte van het BEV-only scenario. De belangrijkste voordelen komen voort uit lagere initiële kosten voor de aanschaf van vrachtwagens (door kleinere batterijen) en het wegvallen van wachttijden voor opladen.

De positieve resultaten zijn echter onderhevig aan grote onzekerheden rond de belangrijkste factoren, zoals de ontwikkeling van de batterijprijzen, haalbare verkleining van het batterijformaat en het aandeel van O-BEV's op de corridors. Het aantal O-BEV's op de ERS-corridor is bijzonder kritisch. Een gunstige business case voor wagenparkbeheerders, ondersteund door lage elektriciteitsprijzen op de ERS, zou kunnen leiden tot meer O-BEV's op de corridor. Maar lage elektriciteitsprijzen op de ERS maken de business case van de exploitant minder levensvatbaar. Omgekeerd kan de vaststelling van hogere energieprijzen om de winstgevendheid van de ERS-exploitant te verbeteren minder aantrekkelijk maken voor wagenparkexploitanten, waardoor het gebruik van O-BEV's langs de corridor afneemt. Dit zou op zijn beurt de positieve sociale KBA in gevaar brengen, waardoor het project minder effectief zou zijn in het behalen van de beoogde voordelen.

Uit de hierboven beschreven resultaten blijkt dat het moeilijk is om een positieve business case op te stellen voor zowel eindgebruikers als ERS-exploitanten. Onder aannamen voor alle inputparameters (inclusief ERS-infrastructuurkosten en batterijkosten) die leiden tot een positief KBA-resultaat vanuit een maatschappelijk perspectief, is er geen overlapping tussen het prijsbereik voor ERS-elektriciteit waarvoor met ERS rendabel is voor eindgebruikers en het bereik waarvoor de business case positief is voor de ERS-exploitant. Om dit op te lossen, kan gebruik worden gemaakt van investerings- of exploitatiesubsidies voor ERS-exploitanten, waardoor de elektriciteitsprijs voor ERS-gebruikers effectief wordt gesubsidieerd. Het omslagpunt waarop ERS aantrekkelijk wordt voor zowel eindgebruikers als infrastructuurexploitanten, hangt uiteraard af van de kosteninput en de veronderstellingen die in de KBA worden gebruikt.

Daarom is verdere beoordeling van de investeringsrisico's nodig. Ook andere effecten, die nu buiten beschouwing zijn gelaten, zouden nader onderzocht moeten worden voor een vollediger MKBA. Tot slot zou de argumentatie rond strategische effecten zoals implementatietijd, versnelling van de energietransitie in wegtransport, en verlichting van netcongestie verder uitgewerkt kunnen worden ter ondersteuning van beleidsbeslissingen.

Summary

Introduction: This report presents a follow-up analysis of the societal costs and benefits associated with the implementation of an Electric Road System (ERS) for trucks in the Netherlands. Earlier studies had left gaps in the assessment of benefits or were not geographically specific. This study is part of the international collaborative project E-CORE, to evaluate the feasibility and benefits of ERS across Europe. The application of ERS technology, which allows for dynamic charging of heavy duty Battery-Electric Vehicles (BEVs) via overhead wires, is compared to a scenario with only static charging infrastructure.

The primary objective of this project is to understand the societal impacts, costs, and benefits of implementing ERS, specifically for two separate freight corridors from Rotterdam: towards Germany (Corridor 1) and towards Belgium (Corridor 2). The study aims to assess whether ERS has the potential to reduce costs and improve efficiency in the logistics sector, compared to the scenario with only static charging, where the same reduction of direct greenhouse gas emissions is achieved. A sensitivity analysis examines various factors that could impact the cost-benefit outcomes, such as construction costs, energy consumption, battery prices, battery sizes, and the number of O-BEVs (Overhead Battery Electric Vehicles) on an ERS corridor.

Methodology: The analysis follows a systematic process as prescribed for cost-benefit analysis in the Netherlands:

1. Definition of base case (scenario 1: stationary charging-only) and project alternative (scenario 2: with ERS in addition to static charging).
2. Development of the storyline for the cost-benefit analysis.
3. Data collection and model creation.
4. Interpretation of results and reporting.

The main potential benefits of ERS, compared to battery electric vehicles with static charging only, lie in operational cost savings due to reduced battery sizes and the absence of waiting times for drivers to charge. The main cost lies in the investment in, and the operation and maintenance of ERS infrastructure: the overhead wires, grid connections, and the costs of the pantograph equipment to connect trucks to overhead wires. The focus of the CBA has been on this main cost-benefit mechanism.

Important assumptions and limitations: In this project, we build upon existing knowledge, using data from previous studies to develop the Social Cost Benefit Analysis. In certain areas, we incorporated more recent data to improve accuracy, and we also analysed the influence of some key assumptions on the final outcomes. The approach to specific aspects of the project had to be limited in scope to meet the requirements of a relatively small budget and a tight timeline, ensuring that the study could be completed on time. Although the rules for cost-benefit analysis have been followed as much as possible, the emphasis in this study was on the financial and monetizable effects. A deeper analysis of various imponderables and the complex market mechanisms associated with electrification of road freight has not been conducted.

With this in mind, the following considerations, assumptions and limitations apply to the analysis:

- Battery costs:
 - The differences in vehicle costs of BEV and ERS trucks (O-BEV) are strongly influenced by battery prices (€/kWh) and differences in battery size. It is expected that smaller batteries will be used in O-BEVs, but it is unknown to what extent. A more detailed analysis of origins and destinations and of variations in the daily usage of trucks using the corridor is needed to better assess the potential for battery size reduction associated with ERS. This, however, was not possible with the data available for this project. In this study, we assume 700 kWh batteries for BEVs and 150 kWh batteries for O-BEVs using ERS.
 - Also, battery prices in future years are uncertain. Estimates vary between 40 and 120 €/kWh in the period 2030-2050, which has considerable implications for the business case. For the central estimate in our calculation, we used the most recent study (Link et al., 2024), which takes into account several previous studies. A sensitivity analysis has been carried out with respect to variations in battery price developments and battery size reduction.
- Infrastructure costs: based on several publications, a plausible range for the costs of ERS charging infrastructure was established. These costs are uncertain, however, and can vary between 1M€/km and 4 M€/km (in two directions). As the central value for our calculation, we assumed a fixed price, as calculated in a previous study by Movares (2020). However, also for this parameter a sensitivity analysis has been carried out.
- The analysis is sensitive to both the number of trucks on the corridor and the uptake scenario for BEVs and O-BEVs. However, demand for ERS is not modelled based on price sensitivity or the operational profiles of vehicles on the corridor, which is a notable limitation. Instead, it is assumed as a fixed, varying percentage of the total truck flow expected on the corridors, without accounting for factors such as price elasticity or the specific usage patterns of trucks that might impact ERS demand more accurately.
- Electricity Costs: Public and private charging locations will have different energy prices. It is uncertain to what extent electricity prices will fluctuate during the day and night, and what impact this will have on both dynamic and static charging prices. The effects of electricity prices and day/night variations were not investigated in this study. Night-time charging may result in lower renewable energy use, which could lead to higher prices. In this study, we assume a fixed price for grid energy for both ERS and depot charging, and a fixed electricity price for users of the ERS, regardless of utilization.
- Time effects: The ERS eliminates the need for stopping to charge, thereby avoiding any potential waiting time associated with static charging. This benefit has been accounted for by incorporating the value of time into the calculations.
- Depot charging: The need to build infrastructure for overnight charging has been considered as an additional cost for logistics companies. This includes the investment required to enable overnight charging for their vehicles. The development of public charging infrastructure and its potential effects of ERS deployment on public charging availability were not accounted for in this analysis. It is assumed that a single corridor will not significantly affect public charging infrastructure deployment, as the charging stations will continue to serve other users who are unable to utilize the ERS.

- Weight effects: An effect that is not considered concerns the vehicle weight reduction enabled by O-BEV compared to BEVs. David Cebon from the University of Cambridge mentioned that a 2024 UK study indicates that the payload reduction effect of large batteries in electric trucks could reach up to 25%. This reduction could result in an equivalent increase in trip costs for weight-limited transport. ERS could help to alleviate this issue by reducing the need for large onboard batteries, thus preserving payload capacity.
- Additional and relatively minor effects are expected from e.g. visual intrusion of the overhead lines on highways (which can be considered a social cost) but these have not been included.
- Strategic arguments in favour of ERS include the potential for lower reliance on critical raw materials for batteries, alleviation of grid congestion, and faster rollout of sufficient charging infrastructure. These were not included in the quantitative analysis. Also, potential environmental benefits, which might occur if ERS enables accelerating the energy transition for road freight transport, have not been assessed.

Results: The calculations indicate that the use of O-BEV's can be a financially better solution for society than the BEV only scenario, depending on the conditions. With our assumptions, the initial investments for both corridors, from the Port of Rotterdam to Germany (Corridor 1) and to Belgium (Corridor 2), are estimated at €590 million for 180 km of ERS and €239 million for 72 km of ERS, respectively. In the base scenario for the O-BEV uptake the Net Present Value (NPV) of all capital and operational costs in the period 2030-2060, considering a discount rate of 3%, is €6.51 billion for Scenario 1 (Baseline) and €6.34 billion for Scenario 2 (ERS alternative) on Corridor 1. For Corridor 2, the NPV of all capital and operational costs in the period 2030-2060 is €3.11 billion for Scenario 1 and €2.98 billion for Scenario 2. Figure 0.1 shows that, depending on the uptake of O-BEV's on the corridors, it can be advantageous to build the ERS infrastructure.

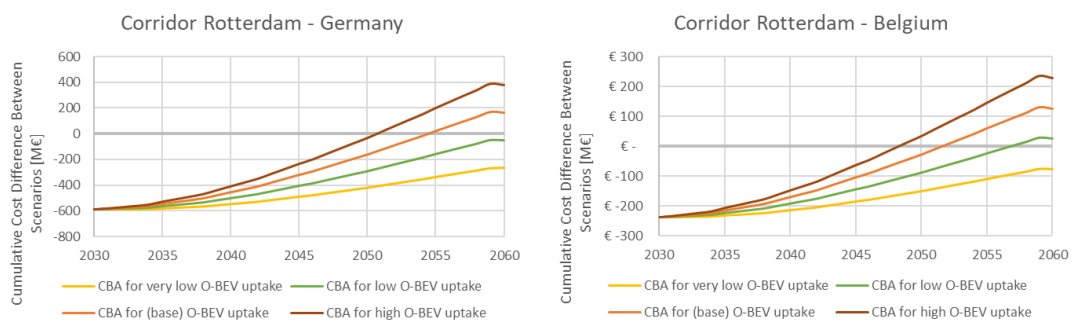


Figure 0.1: The Social CBA outcome shows the difference between the cumulative NPV of the costs for the BEV-only scenario and O-BEV scenario for Corridor 1 (Rotterdam-Germany) and Corridor 2 (Rotterdam-Belgium) with 4 different O-BEV truck uptake scenarios (Very low = 50% of uptake in the base scenario, Low = 75% of uptake in the base scenario, Base scenario, and High = 125% of uptake in the base scenario).

Table 0.1 and Table 0.2 show two key factors that influence the final result of the Social CBA outcome: variations in the development of battery prices and in the cost of ERS infrastructure per kilometre.

Table 0.1: The table shows the impact of five different battery price evolutions and a range of assumptions for the ERS infrastructure costs on the Social CBA (difference between NPV of the costs for the BEV-only scenario and O-BEV scenario) for the ERS corridor from Rotterdam to Germany. The battery price scenarios are arranged from lowest to highest cost, with the Mauler et al. (2021) scenario representing the lowest battery price option. The central assumptions for battery prices and ERS infrastructure costs are underlined to highlight the baseline comparison point in the analysis.

Corridor 1		ERS infrastructure cost per km in both directions [M€/km]									
NPV for scenario difference [M€]		1.00	1.50	2.00	2.50	3.00	<u>3.28</u>	3.50	4.00	4.50	5.00
Battery price	Mauler et al. (2021)	476	371	265	159	53	-6	-53	-158	-264	-370
	Near Market	506	401	295	189	83	25	-23	-128	-234	-340
	<u>Average All (Base)</u>	648	542	437	331	225	<u>166</u>	119	14	-92	-198
	Scientific	670	564	458	352	247	188	141	35	-71	-177
	Other	713	607	501	395	290	231	184	78	-28	-134

Table 0.2: The table shows the impact of five different battery price evolutions and a range of assumptions for the ERS infrastructure costs on the Social CBA (difference between NPV of the costs for the BEV-only scenario and O-BEV scenario) for the ERS corridor from Rotterdam to Belgium. The battery price scenarios are arranged from lowest to highest cost, with the Mauler et al. (2021) scenario representing the most cost-efficient option. The central assumptions for battery prices and ERS infrastructure costs are underlined to highlight the baseline comparison point in the analysis.

Corridor 2		ERS infrastructure cost per km in both directions [M€/km]									
NPV for scenario difference [M€]		1.00	1.50	2.00	2.50	3.00	<u>3.28</u>	3.50	4.00	4.50	5.00
Battery price	Mauler et al. (2021)	236	194	151	109	67	43	24	-18	-60	-103
	Near Market	251	209	166	124	82	58	39	-3	-45	-88
	<u>Average All (Base)</u>	322	280	237	195	153	<u>129</u>	110	68	26	-17
	Scientific	333	290	248	206	163	140	121	79	36	-6
	Other	354	312	270	227	185	161	143	100	58	16

From a societal perspective, cost parity can be achieved with sufficiently favourable conditions. In our base scenario, the Rotterdam-Germany corridor performs better than the corridor toward Belgium as it is expected that it will have more (freight) traffic, as shown in Chapter 4. However, the Rotterdam-Germany corridor is also more sensitive to negative outcomes if construction costs increase or if battery prices drop. To evaluate this, a sensitivity analysis was conducted to account for these key uncertainties. The BEV-only scenario is a better option in scenarios with low battery prices and high ERS infrastructure investment costs, as shown in Tables 0.1 and 0.2. The O-BEV scenario is a better solution if the battery price stays high or the ERS infrastructure costs are low.

To calculate the CBA for the business case of fleet operators we used a private discount rate of 9.5%. For assessing the business case of ERS operators we consider them as public parties and use an interest rate of 3%.

The result of the CBA for the ERS operator is negative under our assumption of the electricity price that is charged to users of the ERS. For the CBA to be positive, the electricity price for the users of the ERS would need to be above €1 per kWh, as shown in Table 0.3.

Table 0.3: Net Present Value of total costs and revenues for the public ERS operator over a 30-year operational period, for different values of the electricity price charged to end users.

Cost of charging on ERS [€/kWh]	NPV Corridor 1 [M€]	NPV Corridor 2 [M€]
0.2	-695	-285
0.3	-624	-251
0.4	-552	-217
0.5	-481	-183
0.6	-409	-148
0.7	-337	-114
0.8	-266	-80
0.9	-194	-46
1.0	-122	-12
1.1	-51	22
1.2	21	56

The business case for end-users is shown in Table 0.4, as function of the price for charging electricity from the ERS. For all other input parameters (e.g. battery cost development) central values are used. For electricity prices on the ERS below €0.7 per kWh, there is a positive business case for investing in O-BEVs and using the ERS. If the cost of charging at the ERS exceeds €0.7 per kWh, the financial incentive for fleet operators to adopt ERS disappears, meaning that the business case for using ERS becomes negative. In that case, the cost advantage from purchasing cheaper trucks (due to the smaller battery), are more than outweighed by the energy costs during operation.

Table 0.4: The effect of the electricity price for charging on the ERS on the NPV of the costs for fleet operators over a period of 30 years of operation on the ERS.

Cost of charging on ERS [€/kWh]	NPV Corridor 1 [M€]	NPV Corridor 2 [M€]
0.2	370	176
0.3	298	142
0.4	226	108
0.5	155	74
0.6	83	39
0.7	11	5
0.8	-60	-29
0.9	-132	-63
1.0	-204	-97
1.1	-275	-131
1.2	-347	-165

Conclusion and recommendations: The study investigates the potential benefits of implementing ERS infrastructure on two freight corridors from the port of Rotterdam: towards Germany and other towards Belgium. Charging electricity from the overhead wires of the ERS is assumed to replace static charging for a part of the electric trucks driving on the corridors. The findings indicate that, under favourable conditions, investments in ERS can be socially cost-effective in comparison with the BEV-only scenario. The primary drivers of these benefits are a lower initial investment for the truck purchases (due to smaller battery size) and elimination of waiting times for recharging.

However, the positive outcomes are subject to significant uncertainties surrounding key factors, such as battery price developments, feasible battery size reductions, and the share of O-BEVs on the corridors. The number of O-BEVs operating on the ERS corridor is particularly critical. A favourable business case for fleet operators, supported by low electricity prices on the ERS, could lead to more O-BEVs on the corridor. However, low electricity prices on the ERS make the operator's business case less viable. Conversely, setting higher energy prices to improve the ERS operator's profitability could make the system less appealing to fleet operators, reducing O-BEV adoption along the corridor. This would, in turn, jeopardize the positive social CBA, making the project less effective in achieving its intended benefits.

The results described above indicate that creating a positive business case for both end users and ERS operators is difficult. Under assumptions for all input parameters (incl. ERS infrastructure costs and battery costs) that lead to a positive CBA outcome from a societal perspective, there is no overlap between the ERS electricity price range for which using ERS is profitable to end users and the range for which the business case is positive for the ERS operator. To solve this, investment or exploitation subsidies to ERS operators could be used, effectively subsidizing the electricity price for ERS users. The tipping points for ERS to become attractive to both end-users and infrastructure operators obviously depend on the cost inputs and assumptions used in the CBA.

Therefore, the results should be further assessed to allow an evaluation of investment risks. Also, several disregarded impacts could be better explored to complete the picture of a full CBA. Finally, the argumentation around strategic effects, such as implementation time, acceleration of the energy transition for road transport, or relief of net congestion, could be deepened to support decision-making.

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1 Introduction

This chapter presents the background, the objectives, and the research questions of the study. We place the project in relation to other running projects and introduce the scope of the study.

1.1 Background

Electric road systems (ERS) are promising technologies for the dynamic charging of battery-electric vehicles (BEVs), specifically trucks. In the context of fleet electrification to reduce GHG emissions from freight transport, ERS is complementary to the baseline of stationary charging with public and/or private chargers. Expected benefits include savings for the logistics sector in terms of time (due to reduced charging) and vehicle costs (due to smaller batteries). Recently, several countries have launched initiatives to explore the feasibility and impacts of ERS. The technology is seen as ready for implementation. The outcomes of the first pilots showed encouraging results but with some mixed outcomes. An important remaining question concerns the framework conditions for international implementation, where network investments and charging technologies would need to be aligned across several countries.

In this context, the German government launched the E-CORE project in 2023, with participation from The Netherlands, Austria, and Hungary. Together, these countries are studying the opportunities for an international corridor between the port of Rotterdam, the Ruhr industrial area, Austria, and Budapest. In The Netherlands, the Ministry of Infrastructure and Water Management has already commissioned studies, including (Movares, 2020), (SSU Case Team, 2021) and (Decisio, 2022) as well as a study on ERS acceptance by the Dutch public (Draagvlak ERS onder het Nederlandse publiek¹) in 2023. The present project was commissioned as the Dutch contribution to the E-CORE project, exploring the connection of the Netherlands to the international corridor through a cost-benefit analysis.

1.2 Project objective

The objective of the project is to gain insight into the costs and benefits of ERS implementation in the Netherlands. The focus is on the first implementation on corridors from the Rotterdam port area towards the neighbouring countries, Belgium and Germany, for use by trucks.

The main research question of this study is:

What are the costs and benefits of an ERS corridor for trucks between the Netherlands and its neighbouring countries, implemented in addition to stationary charging facilities, compared to a scenario in which battery electric trucks only use stationary charging?

¹ [Draagvlak ERS onder het Nederlandse publiek | Rapport | Rijksoverheid.nl](#)

1.3 Scope of the study

The scope of the study is bound by the following choices, established together with the client:

- We compare a scenario with the BEVs charging only at the depot and public charging stations (zero-alternative) to a scenario where part of the BEVs are replaced by O-BEVs (Overhead BEVs) which are charged using an ERS Catenary System (project alternative).
- Two transport corridors are analysed separately:
 - Port of Rotterdam towards the German border (180 km);
 - Port of Rotterdam towards the Belgian border (72 km).
- Time frame: 2030 to 2060
- Monetary units: Costs and benefits expressing 2030 Net Present Value (NPV) with a discount rate of 3% p.a. (European Commission, 2023a) for the societal perspective and ERS operators' perspective and 9.5% for the perspective of end-users (logistics operators) (European Commission, 2021, 2023b).
- For the ERS, we consider only the option with conductive overhead wires. A technology comparison with other ERS systems is not part of this report. Therefore, inductive charging and rail-conductive charging technologies are not included in this CBA. Previous studies by SSU Case Team, (2021) and PIARC (2023) explored these alternatives more deeply.
- The CBA considers the total investment for the ERS infrastructure to be made in 2030, the year when the complete system is assumed to be ready. In reality, given the construction time, part of the ERS infrastructure could be in operation before the full 72 km or 180 km corridor is completed. We do, however, not consider any potential costs or revenues that could arise from the utilisation of the ERS infrastructure before 2030.

2 Literature analysis

In Sweden, many studies on ERS have been carried out. Rogstadius (2022) explored interaction effects between diesel-powered and battery-powered heavy trucks, dynamic vehicle charging via electric roads, and static charging via other forms of charging infrastructure. Along stretches where electric roads are built, it is assumed that 60–100% of the heavy traffic will use the infrastructure. The reduced need for battery capacity results in lower capital costs for vehicles, and lower vehicle weight. This, in turn, results in cost advantages for electric road-adapted vehicles compared to conventional battery-electric vehicles. Börjesson et al. (2021) evaluated the social benefits of electric roads in the Swedish highway network. The authors modelled the behaviour of the carriers, determining the optimal shipment sizes and transport chains, including mode and vehicle type. Electric roads appear to provide a cost-effective means to reduce carbon emissions from heavy trucks significantly. The authors mentioned that investment and maintenance costs are uncertain and that, in the long run, battery development or hydrogen fuel cells may reduce the benefit of such roads.

Olovsson et al. (2021) analysed the impacts of static charging and ERS on the Swedish and German electricity systems. They compare scenarios of nighttime charging at carriers with daytime charging with ERS. The results showed that the additional electricity load arising from the large-scale implementation of ERS, depending on the model and scenario, can be met by wind power in Sweden (40–100%) and both wind (20–75%) and solar power (40–100%) in Germany. As can be expected, compared to full nighttime charging, ERS increases the peak power demand (i.e. the net load) in the electricity system. Therefore, when using ERS instead of full nighttime charging, there would be a need for additional investments in peak power units and storage technologies. Gaete-Morales et al. (2023) compare ERS with daytime stationary charging and arrive at different conclusions, calculating the power sector effects of static and dynamic solutions. Compared to public charging over the daytime, ERS has similar demands on the grid, but these can be significantly lowered when ERS is combined with Vehicle-to-Grid (V2G) technology.

Morfeltdt et al. (2022) investigated the carbon footprint impacts of full fleet electrification of Swedish passenger car travel in combination with different charging options, including ERS. The research applies a prospective life cycle analysis framework for estimating carbon footprints of vehicles, fuels, and infrastructure. Their results show that implementing ERS on selected high-traffic roads could lead to significantly avoided emissions in battery manufacturing compared to the additional emissions in ERS construction. ERS combined with stationary charging could enable additional reductions in the cumulative carbon footprint of about 12–24 million tons of CO₂ over 30 years (2030–2060) compared to an electrified fleet only relying on stationary charging. Shoman et al. (2022) used real-world car movement data and detailed spatial analysis to explore to what extent ERS could displace stationary charging if it is available for BEVs and its expected benefits. It was found that a mix of ERS and home charging would achieve the most significant benefits. ERS with home charging reduces the required battery range by 62–71% in the main scenarios, and the net savings from smaller BEV batteries exceed the cost of ERS. Utilizing ERS could also reduce peak BEV charging by distributing charging throughout the day. The impacts of reduced battery size, when applying ERS to trucks, is in our study as far as costs are concerned.

The consequences of smaller batteries on various life cycle impacts could be a subject for further study.

Qiu et al. (2022) evaluated the economic feasibility of heavy-duty electric trucks that are supplemented by ERS, as well as their technical aspects. A case study is conducted for Canada, and various costs are calculated and analysed. Results show that the operational costs for a heavy-duty electric truck on the ERS ranges from \$ 0.242 to 0.666 per km. If fuel and vehicle prices evolve as predicted between now and 2050, ERS could become an economically feasible form of road transport, especially for the heavy-duty trucks segment, resulting in energy savings and, thus, significant CO₂ emission reductions compared to diesel trucks.

Coban et al. (2022) claim that ERS can not only overcome range anxiety but also, cost-effectively, electrify heavy-duty transport in Turkey. The case study provides a hypothetical example with and without an electric road, covering a total of 26,011 km of highways and main roads. According to the authors, if a large battery was replaced with a smaller battery for each new vehicle sold, after 3 years, enough savings would be made to electrify all highways and main roads in Turkey.

Hanesch et al. (2022) performed a Life Cycle Assessment (LCA) for an O-BEV using real data from an ERS field trial in Germany, including vehicle, infrastructure, and energy carrier of regional freight transport. The comparison with conventional diesel trucks shows GHG savings of about 22%. This is important, since not only the fuel burning in the use phase causes emissions, but the whole life cycle of energy carriers, vehicles, and infrastructure should be taken into account. An LCA comparing the emissions from BEV trucks charging at static stations and the ERS infrastructure could add great value to the social benefit analysis of these technologies.

A study from Transport & Environment (2021) also analysed the system costs and total cost of ownership (TCO) of vehicle technologies that can decarbonize Germany's long-haul truck fleet. By comparing BEVs using static chargers and ERS, hydrogen-powered fuel cell electric vehicles (FCEVs), diesel vehicles powered by liquid e-fuels (ICEVs_PtL), and vehicles powered by gaseous e-fuels (ICEVs_PtM), the study concluded that, based on today's assumptions, expected market developments and the foreseeable technology cost reductions, BEVs charging at static chargers and ERS are likely going to be the most cost-effective pathway to replace the vast majority of today's diesel-powered vehicle fleet. Automotive batteries are experiencing a self-reinforcing dynamic that will drive down their costs due to the accelerating ramp-up in the passenger car market, which is expected to spill over to the urban, regional, and long-haul trucking segment.

In the UK, Ainalis et al. (2020) set out the case for a nationwide rollout of ERS through the 2030s. A total investment in the region of £19.3 billion would be required to electrify almost all the UK's long-haul freight vehicles, which do 65% of all road freight movements in the UK. The estimated CO₂ savings would be 13.4 MtCO_{2e} per annum compared to diesel vehicles, along with substantial air quality benefits. Moreover, the investment by vehicle owners in the pantograph electric vehicles could be paid back in 18 months, through lower energy costs, ensuring rapid take-up by the road haulage industry. The electrification infrastructure could pay back its investors in 15 years, through the profit margin on electricity sales.

Aronietis and Vanelslander (2023) modelled the deployment of ERS on the Flemish road network in Belgium to identify its economic impacts for the road haulage industry, their clients and wider society under different technology adoption scenarios. By comparing O-BEVs with BEVs, diesel, LNG, and hydrogen powered trucks, their results showed that ERS has the potential to be developed into an economically sustainable way of decarbonizing road freight transport. It offers considerable economic incentives for all the involved stakeholders and is beneficial to society as a whole.

In The Netherlands, Bakker et al. (2023) analysed the adoption potential of different ERS network designs, specifically contrasting dense infrastructures with longer ERS corridors. Their results showed that corridors offer superior performance in terms of the distance travelled over the ERS infrastructure while dense networks attract more, but shorter trips. These differences in performance indicators have important implications for policymakers when considering the financial viability and environmental impact of different ERS network designs.

Movares (2020) examines to what extent the application of ERS within freight transport is an attractive option for the Netherlands. To this end, diesel and LNG vehicles have been compared with battery electric vehicles with a fuel cell (FCEV), with a large battery (BEV), with power supply via an overhead line (O-BEV), and with a diesel-hybrid variant (O-HEV). The main conclusions of this study are: Dynamic charging with an overhead line (O-BEV), like the BEV and FCEV drive concepts, has the potential to contribute to the climate objectives of the Dutch government. However, there are too many uncertainties to express a preference for one of these concepts. Financially speaking, the FCEV, O-HEV, O-BEV and BEV options do not appear to differ significantly: the Total Cost of Ownership (TCO) varies between 1.0 million and 1.1 million Euro per truck over its lifetime. Based on these calculations, no preferred technology can yet be identified: the differences lie within the uncertainty margins.

Decisio (2022) shows how an ERS network on the main motorways in the Netherlands can be profitable under certain conditions. Based on cost recovery rates for the use of the ERS network, a sufficiently large number of transport operators may find it attractive to invest in ERS trucks instead of just BEVs, and also instead of diesel or hydrogen trucks. From the ERS operator perspective, the study concludes that an ERS network on a single corridor is not viable. The major disadvantage of ERS is that it requires the immediate construction of a large network, which will only become profitable if it is sufficiently well used. This will only happen if, for the end-user, O-BEVs have advantages over BEVs. The main threats to the success of an ERS network are faster-than-expected improvements in batteries (range and weight), faster-than-expected reductions in battery costs, and as a result, lower-than-expected use of the ERS system.

Based on the presented literature analysis, where the studies focused on the comparison of ERS with other energy carrier alternatives, our study is motivated by the lack of a cost-benefit analysis comparing two options for charging electric trucks, the stationary charging system and the dynamic charging with ERS.

3 Methodology

Building on the previous studies done in the Netherlands (Movares, 2020), (SSU Case Team, 2021) and (Decisio, 2022), as well as the cooperation with the E-CORE project, this analysis incorporated available knowledge on the topic of ERS. Following the CBA guide (European Commission, 2014) and the Dutch national guidelines for CBA (Romijn and Renes, 2013), a compact CBA approach (in the Netherlands, known as KKBA – Kengetallen KBA) was developed that fits within the scope and budget of the project. The study focuses on the social cost-benefit analysis (CBA) for the selected corridors and examines the incentives for end-users to adopt the ERS. It highlights how different factors, such as financial savings and improved operational efficiency, can motivate logistics companies to utilize the system.

The process used includes the following steps, developed further in subsequent chapters:

1. **Definition of base case and alternative scenario:** Two scenarios are compared:
 - Scenario 1: stationary charging only (base case)
 - Scenario 2: stationary charging combined with dynamic (ERS) charging.
The second scenario is worked out separately for two different corridors.
2. **Preparing the cost-benefit narrative (conceptual model):** The expectation is that ERS trucks will be cheaper to buy and operate, and lighter in weight, with lower space requirements for depot charging infrastructure and less costs associated with charging times. The main additional cost concerns the additional investment needed in ERS infrastructure, along with its maintenance. These costs are all relatively easy to monetize. Hard-to-monetize aspects, which are not considered in this assessment, include the potential acceleration of the energy transition for trucks, the effects on the power grid, and other environmental impacts.
3. **Acquisition of data:** We used the current and predicted traffic flows on the selected corridors. The hourly traffic is based on NDW data² from inductive loop detectors. BasGoed³ data and predictions regarding growth in goods transport are used to estimate the expected future traffic on the corridors.
4. **Cost-benefit analysis:** The analysis considered the costs of building the ERS infrastructure and the expected energy costs determined by the traffic levels and the share of O-BEVs. It also evaluated the expected costs related to purchasing and operating O-BEV trucks, including capital investment, maintenance, and operational costs. The benefits of O-BEV trucks compared to BEV trucks include lower purchasing prices due to battery size reduction, recharging time-savings, and parking space savings.
5. **Interpretation and reporting**

Through this methodology, the study aims to provide a clear understanding of the potential benefits and costs of implementing ERS, guiding policymakers and stakeholders in making informed decisions about the future of sustainable freight transport.

² www.ndw.nu

³ [BasGoed - Basismodel Goederenvervoer](#)

Figure 3.1 presents the conceptual framework of the expected costs and benefits of ERS compared to a scenario with 100% static charging of battery electric trucks, in addition to the factors driving them. Table 3.1 lists the main cost elements that are included in the CBAs from a societal, ERS operator and end-user perspective.

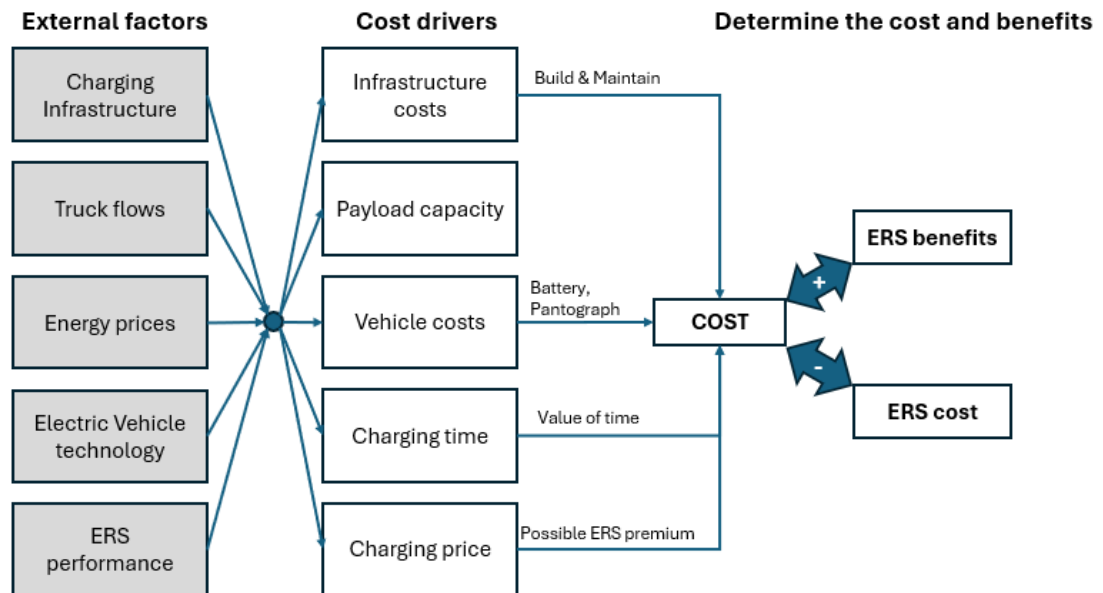


Figure 3.1: Conceptual framework of expected costs and benefits of ERS compared to a scenario with 100% static charging of battery electric trucks.

Table 3.1: List of main cost elements included in the CBA from a social perspective and two business perspectives.

Cost drivers	Social CBA	ERS operator CBA	Logistic operators CBA
Infrastructure investment costs ERS	Yes	Yes	
ERS infrastructure maintenance costs	Yes	Yes	
Residual value ERS	Yes	Yes	
Battery cost	Yes		Yes
Residual value battery	Yes		Yes
Pantograph cost	Yes		Yes
Pantograph maintenance costs	Yes		Yes
Depot charging infrastructure cost	Yes		Yes
Maintenance costs depot chargers	Yes		Yes
Cost of recharging time	Yes		Yes
Cost of parking space	Yes		Yes
Energy consumption costs at the grid	Yes	Yes	Yes
Energy price for charging from ERS		Yes	Yes
Energy price for charging from Megawatt Charging Systems (MCS)			Yes

When evaluating the investment in ERS, we compare a baseline characterised by increased uptake of battery electric trucks using static charging to a scenario with additional overhead catenary ERS infrastructure.

The additional investment and maintenance costs of ERS have to be recuperated with expected benefits from reduced vehicle cost (for example due to reduced battery size), cost reductions due to no waiting times of drivers while using ERS and less investment in overnight charging facilities (infrastructure + parking space). In addition there may be some (second order benefits associated with longer battery life for O-BEVs (Al-Saadi et al., 2022). Additional costs might occur due to detours for drivers to use ERS. We expect these to be small as, for example, detours may also be necessary to use the static charging infrastructure.

Assumptions in the calculations are the following:

- Investments in ERS infrastructure are made in 2030, and the residual value after 30 years is assumed to be 5% of the initial investment costs;
- In 2031, O-BEVs are ready to use the system;
- The O-BEV fleet increases linearly;
- All vehicles are purchased at the start of the year, and if sold, they are sold at the end of the year. Finally, at the end of the 30-year SCBA period, all purchased vehicles are assumed to be sold for their residual value.
- Detours and battery life effects are assumed to be minor and disregarded.

The monetary value of costs and benefits over the period 2030 - 2060 is expressed as the net present value in 2030. The discount rates are in line with the European guidelines: 3% p.a. (European Commission, 2023a) for the societal perspective and for the ERS operators' perspective, and 9.5% for the logistics operators (European Commission, 2021, 2023b). However, given the uncertainty of these discount rates for the future, they are included in the sensitivity analysis in order to evaluate their impacts on the final results.

Based on previous studies, we expect the results to be sensitive to some uncertain input values, especially costs for ERS construction, battery prices, and the share of O-BEVs on the corridor that use ERS. A sensitivity analysis is carried out for these parameters.

4 Corridors

This chapter presents the selected corridors and how they fit into the TEN-T corridor network. The link with the E-CORE project is explained, the available traffic on these corridors is examined, and estimates of the maximum expected traffic and the energy requirements for connecting the ERS corridors to the grid in 2030 and 2060 are reviewed.

4.1 Selected corridors

The corridors were selected in collaboration with E-CORE, a project where the building of the Electric Road System connecting Rotterdam-Frankfurt-Vienna-Budapest is considered. This corridor is part of the TEN-T network and crosses 4 country borders. The E-CORE project will look at the complete corridor and examine its viability in full. The Dutch part of the corridor falls under the North Sea-Rhine-Mediterranean and North Sea-Baltic road corridors.

When choosing the specific corridor towards Germany for this study, we looked at the Annual Average Daily Traffic (AADT) of different vehicle combinations (with a focus on heavy duty vehicles (HGVs)) based on NDW⁴ data, and input from the LMS (Landelijk Model System) and considered the overlap of the different corridors.

Based on the NDW data from November 2023, the AADT on the corridor Rotterdam – Arnhem (A15, A50, A12) towards the German border was around 7900 veh/day (considering 24h).

On the other hand, the AADT on the corridor Rotterdam-Venlo (using the available traffic data from the highways A15, A16, and A73) towards Germany was around 8900 veh/day. This corridor also overlaps with the corridor towards Belgium, thus it is considered to be more favourable for the ERS implementation.

Based on the previous considerations, the corridor towards Germany is considered as connecting the Port of Rotterdam passing through Venlo, as shown in Figure 4.1. The total length of the corridor is 196 km. Disregarding all the bridges and overpasses along the way, it is estimated that the length of the ERS on this corridor will be **180 km**.

⁴ [Nationaal Dataportaal Wegverkeer | Nationaal Dataportaal Wegverkeer \(ndw.nu\)](https://ndw.nu)

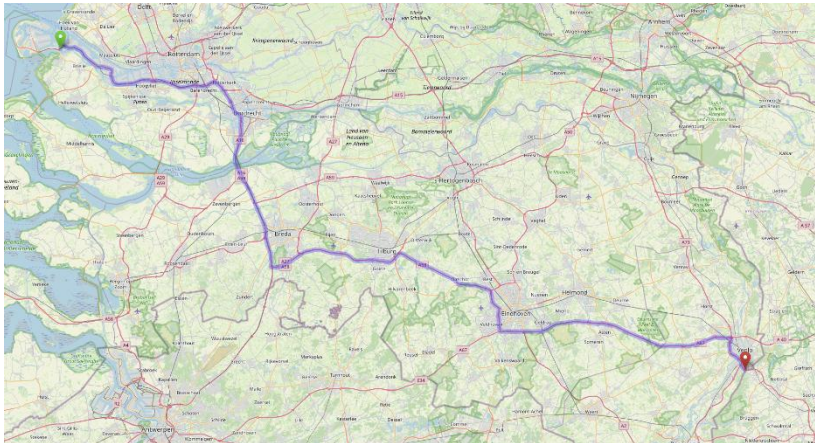


Figure 4.1: Map of Corridor_1 Port Rotterdam – Germany. Source: openstreetmap.org.

The corridor towards Belgium will connect the Port of Rotterdam to the Port of Antwerp. Based on previous research (Aronietis and Vanelslender, 2023), the best route includes the A15 and A16 highways passing through Breda. As mentioned, this overlaps with the previous Corridor_1 at the A15 to A16 until the connection to the A58. The considered Corridor_2 can be seen in Figure 4.2.

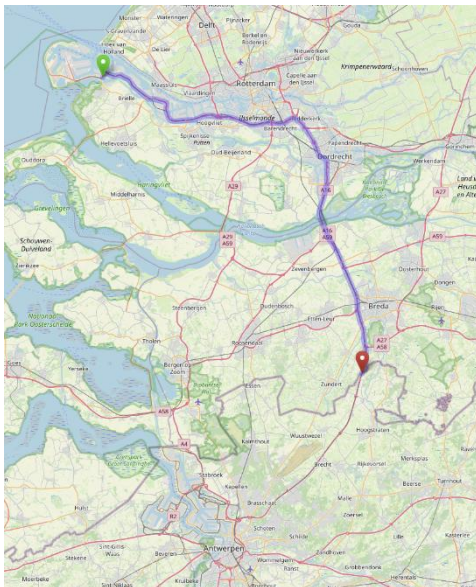


Figure 4.2: Map of Corridor_2 Port Rotterdam – Belgium. Source: openstreetmap.org.

The total length of Corridor 2 on Dutch soil is 84km and the ERS length will be **72 km** (of which about 67 km overlaps with Corridor 1), by disregarding several tunnels, bridges, and overpasses of the A15, just like in the previous case. Additionally, it considers that the ERS will not be built between exits 22 and 20 (approximately 3 km) of the A16 because of the tunnel, overpasses, and limited space. It's assumed that the Dutch part of the ERS corridor will be built by The Netherlands and it will be extended by the neighbouring countries.

4.2 HGV traffic intensity

In this section, we present the traffic on the corridors based on the time of the day, the average values, and total traffic to determine the potential current and future demand on the ERS. We also determine the share of long-distance heavy duty vehicles that would most likely use the ERS.

4.2.1 ERS traffic flow determination

The traffic on the considered corridors was based on NDW⁵ data from November 2023. The NDW data contains 3 vehicle categories based on the length of the vehicle:

Category 1 - motorbike, scooter, passenger car/delivery van < 5.60 m

Category 2 - rigid lorry, rigid bus ≥ 5.60 and ≤ 12.20 m

Category 3 - articulated truck > 12.20 and ≤ 25 m

In our analysis, we focus on Categories 2 and 3, which include all vehicles capable of utilizing the system. Based on available data, the average traffic flow on Corridor 1 is 363 vehicles per hour, while in Corridor 2, it is 373 vehicles per hour (considering 24 hours and the whole corridor length). To project traffic volumes for 2030 and 2060, we assume that the growth in HD vehicle traffic will align with trends in goods transport. According to BasGoed⁶ data, goods transport is expected to grow at an annual rate of 0.9%. Applying this rate to the expected traffic flow, we estimate that by 2030, HGV traffic will have increased to 384 and 394 vehicles per hour for Corridors 1 and 2, respectively, and by 2060, these numbers will have risen to 502 and 515 vehicles per hour. For further details on vehicles per hour (veh/h) and vehicles per kilometre (veh/km), please refer to Figure 4.3 and Figure 4.4.

⁵ [Nationaal Dataportaal Wegverkeer | Nationaal Dataportaal Wegverkeer \(ndw.nu\)](https://ndw.nu)

⁶ [BasGoed - Basismodel Goederenvervoer](#)

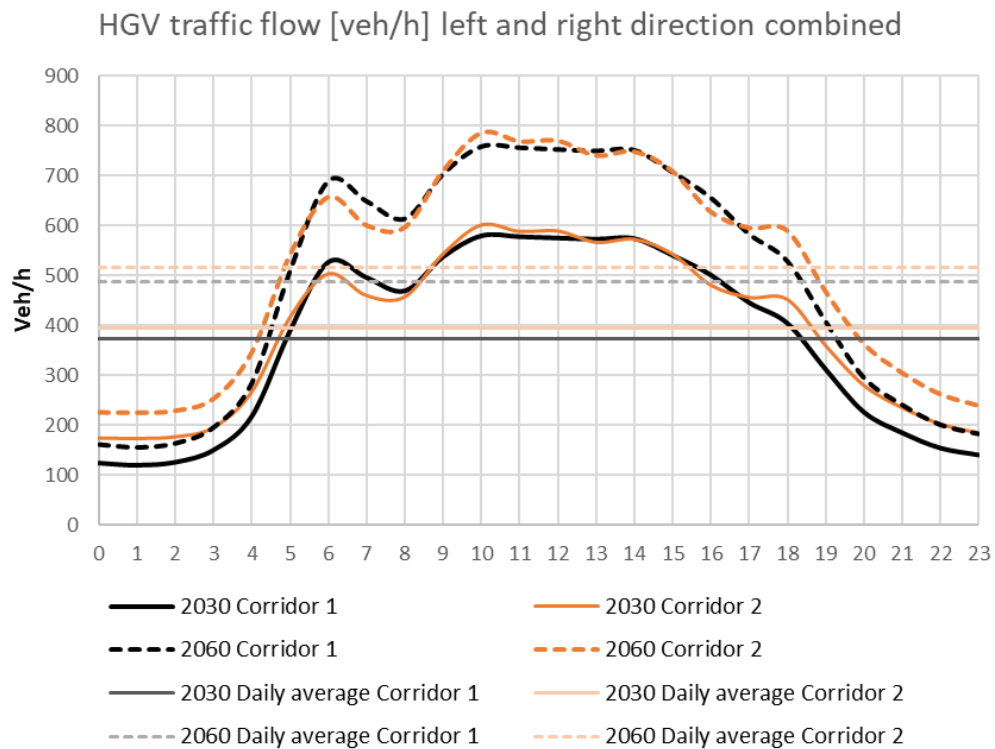


Figure 4.3: Projected HGV and bus traffic flow (veh/h) on the two corridors, averaged over the length of the corridor.

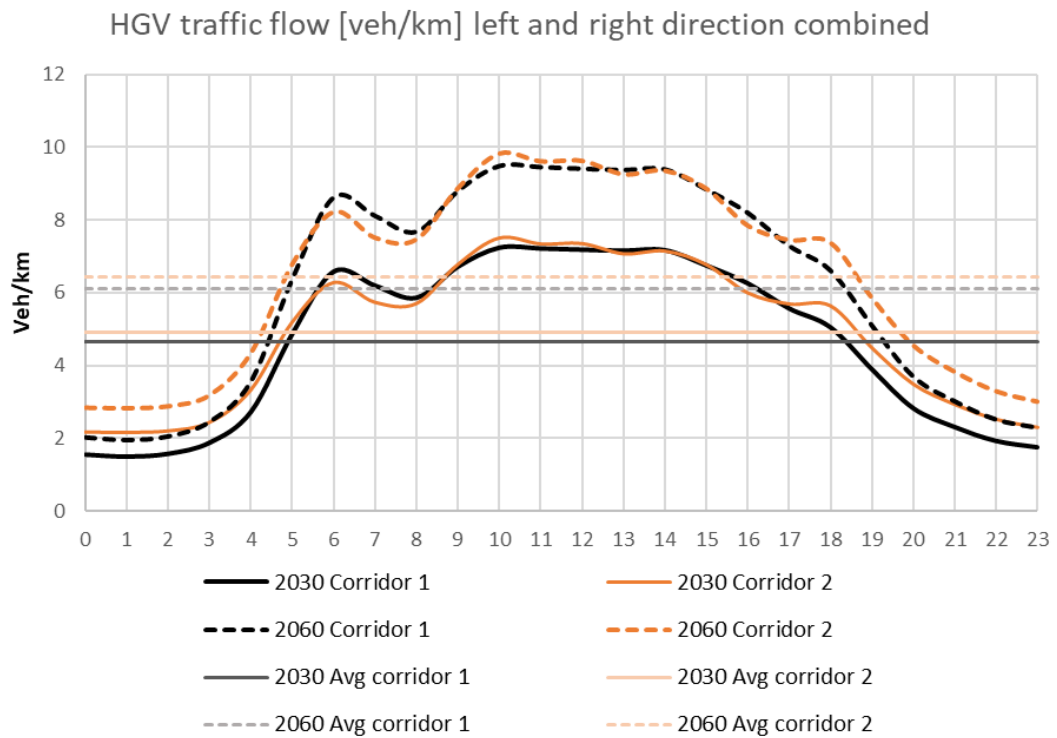


Figure 4.4: Projected HGV and bus traffic flow (veh/km) on the two corridors, averaged over the length of the corridor.

There will be an average peak of 8 vehicles per kilometre⁷ in both corridors in 2030. In 2060, the number of vehicles at a peak is expected to reach 10 vehicles per kilometre.

Using the BasGoed data combined with LMS, an additional analysis of the traffic flow in the selected corridors was conducted. Based on our analysis, we found that approximately 26% of the traffic travels the full length of the corridor. These vehicles originate from various locations, with their destinations ranging from a few kilometres to over 1000 kilometres along the (entire length of corridors on the) TEN-T network. Our analysis also revealed that only around 2% of the total traffic has its entire trip exclusively on the corridor (origin and destination are close by the ERS corridor). This implies that the majority of vehicles using the corridor have origins or destinations outside its boundaries. From this we can see that the assumed battery size of O-BEVs will affect the share of vehicles that are able to use the ERS on the corridor. Figure 4.5 shows the distribution for the share of the trip length that is driven on the corridor from Port of Rotterdam towards Germany on Dutch soil for all trips using that corridor (blue dots). Also shown is the distribution of total trip lengths for all vehicles using parts of the corridor (red bars).

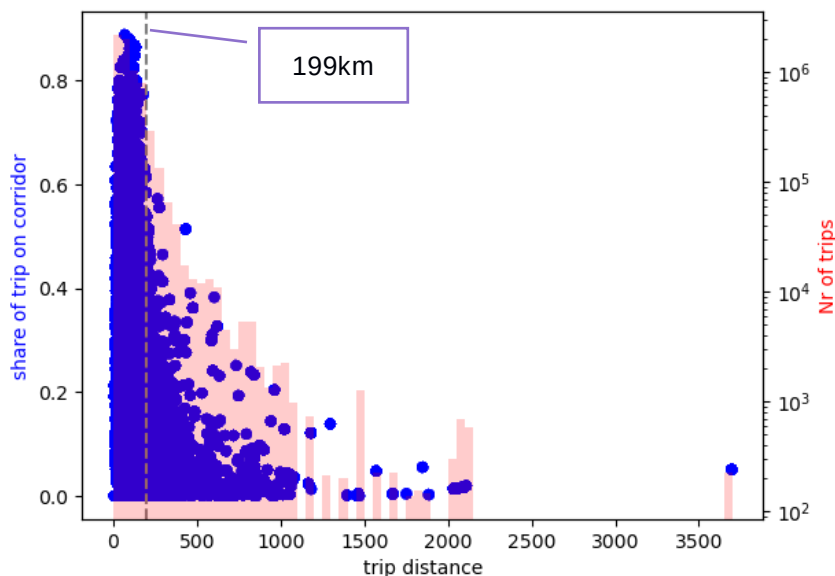


Figure 4.5: Distribution for the share of the trip length that is driven on the corridor from Port of Rotterdam towards Germany on Dutch soil for all trips using that corridor (blue dots), and the distribution of total trip lengths for all vehicles using parts of the corridor (red bars).

4.3 ERS energy demand

In this section, the energy consumption of electric trucks is determined. Given the capacity of the grid connection for the ERS system as used in Movares (2020), we then assess the maximum flow of O-BEVs that the ERS system can cater energy for.

⁷ Temporary surges in truck traffic and energy demand on a specific kilometre of the ERS, which may exceed the system's capacity, should be managed by the control centre. While the specifics of this management system are beyond the scope of this study, these aspects are addressed in the [E-Core study](#).

4.3.1 Grid connection, energy consumption, and system efficiency

Following the assumptions of Movares (2020), connection stations are assumed to be placed every 2 kilometres along the ERS corridor, with each station having a grid connection of 3.6 MVA. According to the literature, the efficiency of overhead line systems ranges from 80% to 95% (Schaap, 2021; PIARC, 2018). Factoring in the AC/DC converter efficiency of 94%, the estimated available power at the converter for trucks is approximately 3.4 MW. For the energy consumed by trucks, we account for additional losses: 4% DC line losses and 5% pantograph losses.

4.3.2 BEV HGVs energy consumption

Based on TNO (2022), which looked at current BEV energy consumption and estimated future consumption based on technology improvements, we determined the average expected energy consumption of O-BEV trucks, as shown in Table 4.1.

Table 4.1: Expected electricity consumption of O-BEV and BEV HGVs at the connection to the drivetrain power electronics not including battery losses and charging losses.

Configuration	Drivetrain	2020 [kWh/km]	2030 [kWh/km]	2040 [kWh/km]
Rigid urban	BEV medium	0.625	0.586	0.564
	BEV large	0.619	0.561	0.550
Articulated regional	BEV medium	1.169	0.989	0.972
	BEV large	1.169	0.992	0.972
Articulated long haul	BEV medium	1.290	1.075	1.058
	BEV large	1.306	1.056	1.028
	Average:	1.23	1.03	1.01
	Average for the 2020-2040:			1.1

For our calculation, we use an average value of 1.1 kWh/km for the HGV's electricity consumption at the connection to the drivetrain power electronics. There are already some trucks performing at this efficiency level⁸. To estimate the energy consumption on the ERS, we accounted for losses in the DC lines and the pantograph, resulting in a consumption rate of approximately 1.2 kWh/km. We also assume that the truck travelling on the ERS can charge its battery, and for each km travelled on the ERS, it stores enough energy to travel 1 km off the ERS (equivalent to 50% of time spent on the ERS). Therefore, the energy consumption on ERS will be 2.4 kWh/km. Considering the maximum current of the pantograph to be 350 A (according to Siemens) and the system voltage 1200 V, the maximum power available for a truck is 420kW, which means that an O-BEV HGV can pick up to 5 kWh/km.

⁸ [Key takeaways from the Battery Electric Truck Trials and Volvo FH Electric excels in first road test | Volvo Trucks](#)

4.3.3 Maximum number of HGV per 1 km (both directions)

Considering the grid power connection and different values for the power consumption by an individual HGV (average when driving / average when driving and charging / maximum), the maximum number of vehicles allowed on the ERS per kilometre in both directions would be as shown in Table 4.2.

Table 4.2: Capacity of the ERS system, based on HGV average consumption when driving / when driving and charging / maximum consumption.

Energy at vehicle [kWh/km]	Energy from ERS [kWh/km]	Power [kW/veh]	Max HGV 2 directions [veh/km]	Max HGV 2 directions [veh/h] on 1 km
1.1	1.21	97	17	1360
2.26	2.48	198	8.0	640
4.6	5.03	402	4.0	320

In Figure 4.6, we can see that in the case of Corridor 2, with a consumption of 2.26 kWh/km, the system can power up to 100% of the expected HGV traffic in 2030 during peak. Considering the day and night spread of traffic in 2030, this would result in a maximum utilisation of 60% of the ERS power capacity. In 2060, the maximum utilisation considering the night and day peak traffic would be 66%. We also see that if the HGV consumption would be bigger (4.6 kWh/km), the ERS system can accept 50% of the 2030 traffic. If the consumption of the truck drops (below 2.26 kWh/km), e.g. due to improved energy efficiency in 2060 and a larger ERS network, which could lead to less need for battery recharging, the system will be able to accommodate more trucks than the expected peak traffic.

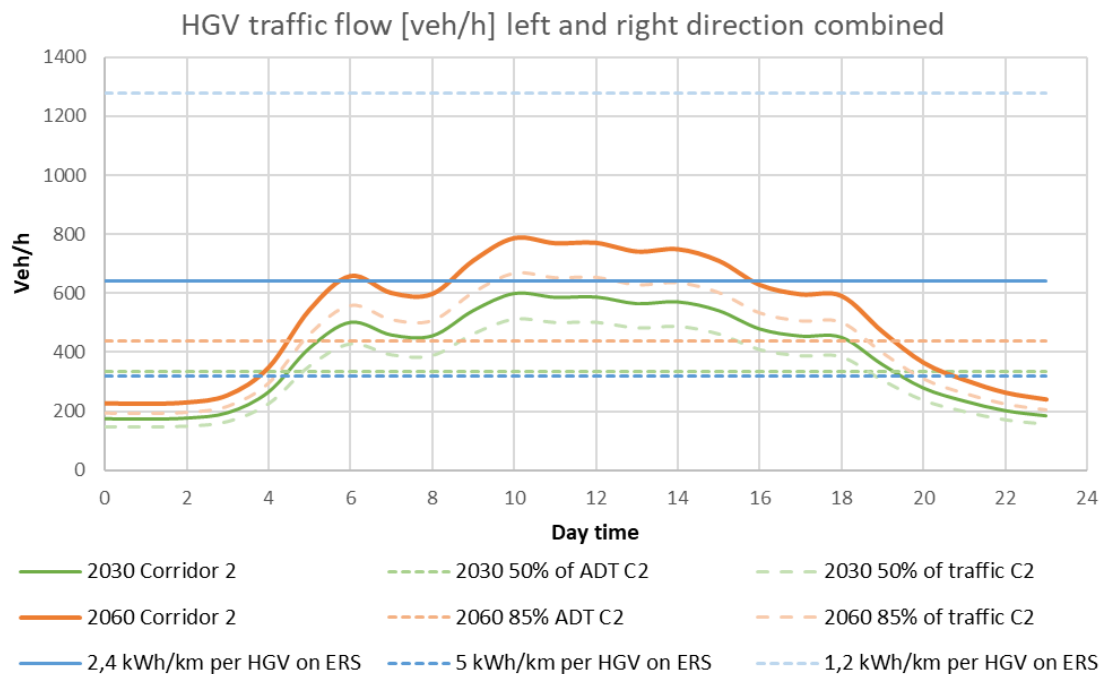


Figure 4.6: ERS capacity considering HGV traffic flows for Corridor 2 (ADT – Average Daily Traffic).

4.3.4 The maximum number of HGVs from the spatial perspective.

If we consider the tractor-trailer length of 16.5 m and apply the 2-second rule for a safe distance at a speed of 80km/h, we can expect a maximum density of 16 tractor-trailer combinations per km. Therefore, we can assume that the maximum occupation in both directions from a space point of view would be 32 HGV. This means that, under normal traffic conditions with vehicles traveling at typical speeds, we should observe no more than 32 HGVs per kilometre (equivalent to 2,560 HGVs per hour) in both directions. As a result, the spatial factor may impose some constraints. In areas where higher concentrations of trucks are expected, local ERS power consumption could increase significantly to levels exceeding the grid connection capacity used in our assessment. This would require expanding the grid connection capacity on specific sections of the ERS to accommodate the higher energy demand.

5 Data input for cost calculations

This chapter outlines the input data used in this study with respect to costs for both stationary and dynamic (ERS) charging systems, including investment, maintenance, and operational costs. It also examines the cost factors for different types of HGVs that can utilize each charging method.

5.1 ERS costs

Movares (2020) focused on the Dutch A15 highway. Since this highway is also part of the corridor in our analysis, we used their cost estimates as a baseline and adjusted them according to the specificities of the corridors considered in our study. The cost adjustment was carried out as follows:

- The cost of overhead lines, which is given per kilometre, remained unchanged.
- The costs related to Converter Stations and Power Supply were adjusted due to a difference in the number of expected stations. The total number of stations per corridor was determined based on the corridor length, and the price per unit was used to recalculate the total cost and the cost per kilometre.
- The Control Centre costs, being a single cost factor, were distributed over the length of the corridor, as it is assumed that the number of centres per corridor remains one.

The resulting costs are presented in Table 5.1. A more detailed calculation is shown in Appendix A.

Table 5.1: ERS CAPEX costs per 1 km in both directions for Corridors 1 and 2.

Components	Movares (121 km)	Corridor 1 (180 km)	Corridor 2 (72 km)
	Cost/km (2 directions)		
Overhead lines (direct construction costs, other costs, reinforcement cable, cross-connection catenary, etc.)	M€ 1.89	M€ 1.89	M€ 1.89
Converter station (incl. permit, access, foundation, etc.)	M€ 0.74	M€ 0.715	M€ 0.738
Control and monitoring	M€ 0.027	M€ 0.021	M€ 0.035
Power supply (individual per station)	M€ 0.645	M€ 0.642	M€ 0.65
CAPEX	M€ 3.31	M€ 3.28	M€ 3.32

The annual operational costs (OPEX), incl. e.g. overall system maintenance, periodic grid connection cost, and wire replacement cost are around 1% of the ERS investment cost, according to Kühn et al. (2017) and Kühnel et al. (2018).

5.1.1 Electricity price on the ERS

For O-BEVs using the ERS the costs for use of the system are assumed to be charged to the fleet operator by means of the price of the electricity drawn from the overhead wires. It is clear that ERS will be economically attractive to end users when energy drawn from the ERS is cheaper than electricity from static charging stations. For a positive business case of ERS for end-users, however, the electricity price does not need to be lower than for static charging as end users also benefit from lower truck costs and lower personnel costs (waiting time when fast charging).

For our calculations we assume a fixed energy price for the ERS users over the entire 2030-2060 period. The CBA from the perspectives of end users and ERS operators are calculated for a range of values for this price, which spans from €0.20 per kWh, i.e. well below the expected future electricity price at static fast charging stations (typically around €0.40 per kWh) to €1.20 per kWh, which is significantly above expected prices for static charging.

Assumptions w.r.t. the electricity price, charged for using the ERS, do not affect the societal CBA. The SCBA the costs of electricity consumption are based on the price of electricity from the grid and all real capital and operational costs involved in supplying that electricity to BEVs and O-BEVs.

In Section 7.3 we present results of assessments of the sensitivity of the CBAs from different perspectives to variations in important input parameters such as battery cost developments. In this sensitivity analysis an electricity price on the ERS of €0.30 per kWh is assumed for assessments related to the business case for end users and ERS operators. This value was initially chosen, based on a comparison with expected cost of static charging at depot, as it makes sure that using ERS is profitable to end-users. In hindsight this value is considered unrealistically low. In the sensitivity analysis, however, that is not a problem as it does affect the absolute level of the cost differential between the scenarios but not its sensitivity to varying the costs of batteries.

5.2 Stationary charging station costs

5.2.1 Cost of charging equipment for depot charging

There are different options for the stationary charging infrastructure to meet the varying needs of battery-electric trucks, including fleet size, daily mileage, and type of operation. These options range from slow alternating current (AC) charging to fast and ultra-fast direct current (DC) charging. The chargers can be located at the operator's terminal (depot charging) and used for overnight charging, or at destination points and used by trucks while loading and unloading. Additionally, public charging can be used during the day or night at publicly accessible locations (Bernard et al., 2022).

In our analysis we assume that the amount of public charging stations on the corridors is the same in both scenarios. As a result, the key cost differences between both scenarios relate to the amount of depot chargers needed and the difference in the average costs of electricity for powering the vehicles. For the BEVs that are replaced by O-BEVs in Scenario 2, the cost difference comes from comparing the electricity cost on the ERS with a combination of the electricity cost for depot and public MCS charging. In this section, the costs of depot charging facilities are specified.

The total cost of depot charging infrastructure includes upfront and operating costs. The upfront costs include the purchase cost, location determination, engineering, and project, management, civil works/installation, digging work, and network connection costs. The land use costs for depot charging installation are presented in the next subsection. Operating costs include periodic grid connection costs, communication costs, insurance, maintenance/repair, and service for user problems. Table 5.2 shows the CAPEX and OPEX of private stationary charging stations chosen for the analysis. These figures exclude land costs and are based on the selected parameters relevant to this study. The lifetime of the chargers was set to 10 years, after which they must be replaced.

Table 5.2: Costs of private stationary 50 kW DC charging stations.

Infrastructure type	Input parameter	Costs	Units
Stationary chargers DC-50 (private stations)	CAPEX (DC-50)	€ 33,833	€
	OPEX (DC-50)	€ 2,169	€/year

Sources: Engelhardt et al. (2023), Penev et al. (2020).

Topsector Logistiek report (2022) says that, given the higher costs associated with public charging, 80% of companies would find night-time depot charging more appealing if they could establish sufficient depot charging infrastructure and secure grid connections. For this analysis, we follow this trend and assume that 80% of charging events will occur at private stations (depot charging), with the remaining 20% occurring at public stations.

We assume that BEVs will be charged overnight at the depot. The vehicles will be connected to a charger upon arrival, requiring one charger per vehicle. This setup ensures that no additional rotation of the vehicles will be needed during the night.

For O-BEVs, it is assumed that logistics companies will use only the ERS infrastructure for charging. This approach reduces the need to build depot-charging infrastructure, which in turn lowers the initial investment costs for logistic operators.

Considering the current challenges related to grid congestion for depot charging, and the availability of low-price energy during daytime charging⁹, we include in the sensitivity analysis how varying the depot-to-public charging ratio influences the overall outcome.

5.2.2 Land use costs for depot charging

The cost of parking space for depot charging is determined based on the land cost and expected extra space if charging infrastructure is installed for depot charging.

The extra space for the charging infrastructure is based on recently built truck-only charging hubs¹⁰. Based on the available information, we looked at the number of parking spaces before and after building the charging hub, as shown in Figure 5.1, Figure 5.2, Figure 5.3, and Figure 5.4.

1. Shell Eindhoven Acht Truck Only Location:
 - Original Setup: 14 parking spaces

⁹ [Gratis stroom en negatieve stroomprijzen| ANWB](#)

¹⁰ [Shell-opent-eerste-truckstation](#) and [First-charging-station-for-electric-trucks-opened-in-the-Port-of-Rotterdam](#)

- Current Setup: 4 charging spots (5 chargers) and 8 parking spaces
- Loss: 1 parking spaces per 2 chargers



Figure 5.1: Shell truck-only location before installation of the charger (Source earth.google.com).



Figure 5.2: Shell truck-only location after installation of the charger (right-hand part of picture).

Truck Parking in Rotterdam:

- Original Setup: 9 parking spaces
- Current Setup: 4 chargers and 8 parking spaces
- Loss: 1 parking space per 4 charger

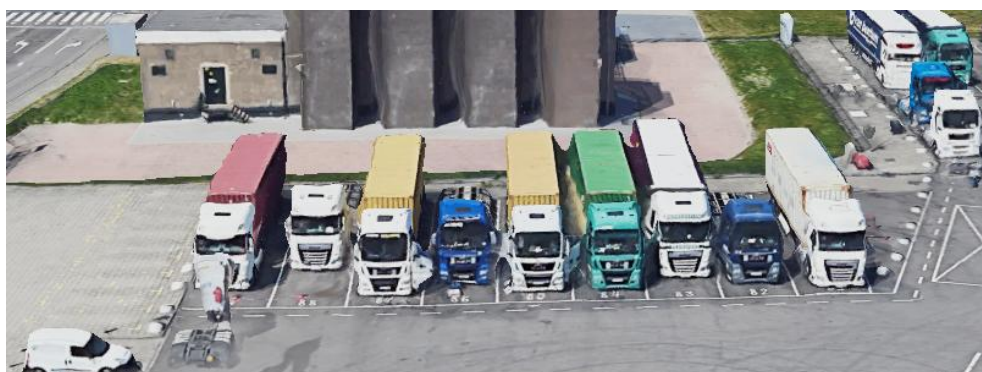


Figure 5.3: Truck Parking in Rotterdam before installation of the charger. (Source: earth.google.com).



Figure 5.4: Truck Parking in Rotterdam after installation of the charger (Source: www.ttm.nl).

Given these specific examples, and acknowledging that other systems might limit the loss of space, we consider a loss of 1 parking space for every 3 chargers. The average price of industrial zone land is €160/m² based on the National Institute for Public Health and Environment (2020) and data from the Dutch Government site (Overheid, 2024). Based on the dimensions of a tractor-trailer, we consider the parking space size to be 52.5 m² per truck (Mikusova et al., 2019), costing €8,400 per parking spot (only capital cost). An additional space of the same size is considered for manoeuvring purposes. We do not speculate on the future value of the land, thus the residual value of land at the end of the project time frame is considered the same as the initial capital investment cost. This means that the only costs included for land use in relation to depot charging are the costs of capital, based on the interest / discount rate times the price of the additionally required land.

We assumed that the O-BEVs charge only on the ERS infrastructure, which means that the logistics companies will not invest in depot charging for O-BEVs, thus not requiring additional parking space for charging of these vehicles.

5.3 BEV and O-BEV truck costs and assumptions

This section outlines the assumptions and inputs used for calculating the investment and operating costs for BEVs and O-BEVs.

5.3.1 Battery cost and size considerations

Given that O-BEVs, using the ERS, need a smaller battery than BEVs, a key factor in the CBA is the purchase cost of the battery, expressed in battery capacity in kWh times a price in €/kWh. Obtaining reliable data on battery prices beyond 2040 is a major challenge, as many studies are either outdated or focus primarily on passenger car batteries. Studies related to ERS conducted before 2019, such as those by Kühn et al. (2017) and Mareev et al. (2017), generally relied on battery price predictions that are now considered outdated.

For this study, we use battery cost projections from a 2024 analysis (Link et al., 2024), presented in Figure 5.5. This analysis consolidates a number of sources, including market prices, academic estimates, and other relevant non-peer-reviewed publications and reports. The data suggests that average battery prices will fall from €174/kWh in 2030 to €99/kWh in 2050.

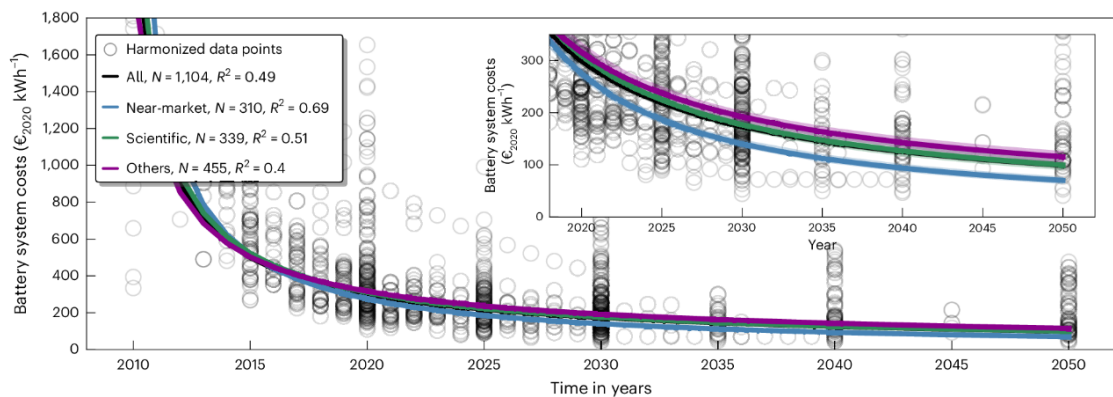


Figure 5.5: System-level costs per kWh of total gross battery capacity. These include, among others, battery and thermal management systems, cell modules, housing, connectors, wiring and assembly. The line names in the chart (Near Market, Scientific, Other) correspond to the sources of information used to create each respective line. The "All" line represents the average trend across all the studies considered in the analysis. Source: Link et al. (2024).

As the lowest battery price option we used the older study Mauler et al. (2021) to check the influence of even lower battery prices than projected in the Link et al. (2024) study. Since available data does not extend beyond 2050, a second-order polynomial approximation was applied to data from 2020 to 2050 to project battery prices for the period from 2050 to 2060. This method provides a consistent basis for calculating future prices in the absence of additional data points. Figure 5.6 shows the base battery price development assumption and the additional 4 different battery price development options that were used in the calculation and in the sensitivity analysis.

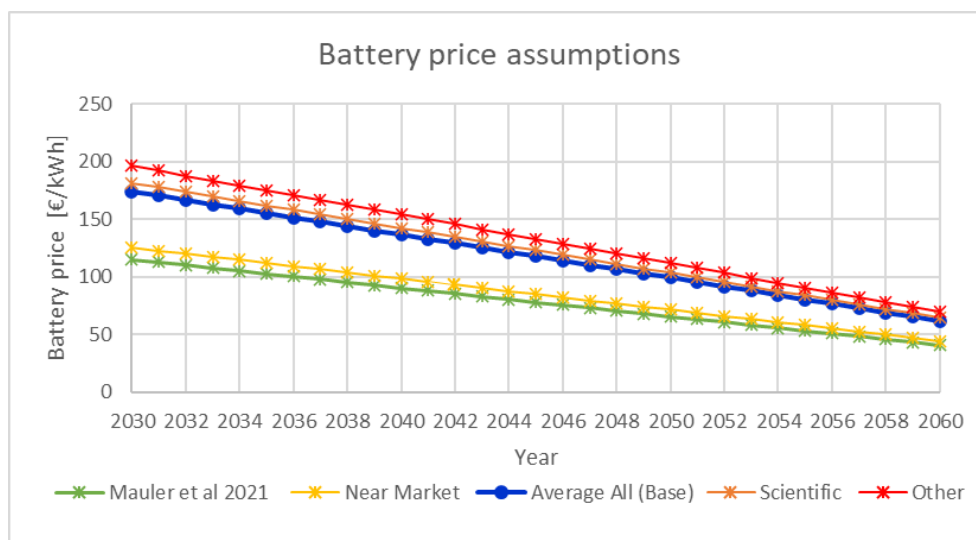


Figure 5.6: Battery price per kWh assumption used in the CBA calculation with 5 options for battery price evolution from 2030 to 2060. To project battery prices beyond the available data points in 2050, a second-order polynomial approximation was applied to data from 2020 to 2050. This approach provides a base to calculate the prices for 2050 to 2060. When zoomed in to the period 2030 to 2060, the trend closely resembles a linear decline. The names of the options remain unchanged from previous studies, reflecting the original sources from which these price estimates were derived.

For our base case analysis of the two selected ERS corridors, we decided to focus on BEVs with a 700 kWh battery and O-BEVs with a reduced 150 kWh battery. This decision is based on the different operational and energy management requirements of these two systems.

For BEVs, the selected 700 kWh battery is based on a balance between the range requirements and battery capacities typically considered in other studies. BEV battery sizes generally range from 350 to 1,100 kWh, as seen in various research, making 700 kWh a representative average within this range. This capacity is appropriate for our focus on shorter corridors, where a very large battery, such as a 1 MWh pack often considered for long-haul applications, would likely not be necessary. As indicated in the TNO 2022 study, larger batteries may be essential for extensive long-haul routes, but for the specific corridors studied, a 700 kWh battery is adequate to complete the mission without needing to recharge mid-route, enabling a comparable operational profile to that of an O-BEV on the ERS.

For determining the expected battery size of O-BEVs, the initial approach for this study was intending to use LMS and BasGoed data. This would involve analysing the number of trips on the selected corridors to estimate the required battery capacity for O-BEVs after they leave the ERS. However, progress with this intended approach was hindered by several challenges.

Firstly, the LMS data does not cover roads outside the Netherlands, making it difficult to predict how far trucks travel after crossing the border. Additionally, aligning the zone coordinates between LMS and BasGoed data proved time-consuming, leaving insufficient time to complete the approach. Given these limitations, further analysis of the datasets was not possible within the available timeframe.

Therefore, for O-BEVs, we based the battery size on average values found in the literature, which suggest battery capacities ranging from 75 to 250 kWh. Based on this range, we selected an average capacity of 150 kWh for our analysis. This battery size enables trucks to complete a round trip of approximately 120 km outside the ERS, making it well-suited for operations that frequently move in and out of electrified corridors. However, the battery size of O-BEVs is a critical assumption that needs further research.

5.3.2 BEV truck cost and assumptions

BEV truck components such as the vehicle chassis, drivetrain, power electronics, and maintenance costs are excluded from the calculations, as these are assumed to be the same for both BEV and O-BEV trucks. Additionally, the total share of electric trucks (both BEVs and O-BEVs) on the corridor is assumed to remain the same in both scenarios. Table 5.3 outlines the specific cost factors for BEVs and O-BEVs that are considered to assess differences in OPEX and CAPEX between the two types of trucks. For estimating the CAPEX and OPEX of BEVs using the corridor, we assume that all trucks operate five days a week, traveling between the Rotterdam region and locations beyond the ERS corridor in Germany or Belgium.

Table 5.3: Input data and assumptions related to the cost and usage of BEVs.

Input parameters	Value	Units	Source
Operational days per year	260	days	
Distance travelled on the Rotterdam – Germany Assumed one-way distance travelled between origin and destination when using the Rotterdam-Germany corridor	252	km	
Distance travelled on the Rotterdam – Belgium Assumed one-way distance travelled back and forward between origin and destination when using the Rotterdam-Belgium corridor	120	km	
Battery capacity	700	kWh	Assumption explained in 5.3.1
Lifetime BEV truck	5	years	Assumption explained in below the table
Residual value BEV truck	5	%	Assumption (Herranz-Matey et al., 2023)
Energy delivered to the drivetrain power electronics	1.10	kWh/km	TNO (2022)
Grid-to-powertrain efficiency (including the battery and charging efficiency)	80	%	TNO (2022); (Kühnel, 2018)
Battery in/out efficiency (including only the battery efficiency)	90	%	TNO (2022); (Kühnel, 2018)
Price per kWh (grid)	0.24	€/kWh	Mobilyze and NAL (2023)
Price per kWh (MCS)	0.60	€/kWh	Assumption based on current high power charging prices ¹¹
Charging/queuing time for public charging	1	hour/event	Assumption includes the time needed for charging, possible waiting, starting of the charging, exiting the highway /stopping to charge.
Depot charging	80	%	Assumption explained in 5.2
MCS charging	20	%	Assumption explained in 5.2

Earlier studies considered a battery lifespan of 1,250 cycles (Kühnel, 2018). It is expected that in 2030, the battery pack will be capable of 2,500 to 3,500 cycles¹². Therefore, we assume an average lifespan of 3,000 cycles. With this assumption, the battery lifespan will exceed the assumed lifetime of the truck.

¹¹ [EAFO-Report-Pricing-of-Electric-Vehicle-Recharging-in-Europe.pdf](#)

¹² [LiFePO4 Battery Cycle Life & Durability \(ecotreelithium.co.uk\)](#)

5.3.3 O-BEV truck cost and assumptions

For the O-BEVs, we assume that the costs of the chassis, drivetrain, power electronics, and maintenance will be comparable to those of BEV trucks (Den Boer et al., 2013); TNO (2022). Additionally, the battery price projections will follow the same trend for both O-BEV and BEV trucks. However, a significant difference lies in the battery size: O-BEVs can operate with smaller batteries. Based on battery sizes reported in other studies (Kühnel, 2018; Rogstadius et al., 2024), we selected an average battery size for our analysis. Considering that logistics companies are likely to prefer trucks with smaller batteries to reduce costs and improve operational efficiency, we assumed a 150 kWh battery for the O-BEVs in our study. This assumption reflects a balance between practical usability on the ERS and minimizing battery investment. With an energy consumption of 1.1 kWh/km, a 150 kWh battery provides the truck with a range of over 120 km outside the ERS system and allows the truck to operate before entering or after leaving the ERS system.

Furthermore, the cost of the pantograph system is found to be between €18,000 and €28,000 (Kühnel, 2018; Ackerman, 2016) in the early stages of deployment (pre-2030), with a projected decrease to between €10,000 and €12,000 by 2050 due to market scale-up (ITF, 2022). For this study we assume a linear decrease from €17,000 in 2030 to €11,000 in 2060 as depicted in Figure 5.7. Table 5.4 presents the various input data and assumptions related to the cost and usage of O-BEVs.

Table 5.4: Input data and assumptions related to the cost and usage of O-BEVs.

Input parameters	Value	Units	Source
Operational days per year	260	days	
Distance travelled on the Rotterdam – Germany Assumed one-way distance travelled between origin and destination when using the Rotterdam-Germany corridor	252	km	
Distance travelled on the Rotterdam – Belgium Assumed one-way distance travelled back and forward between origin and destination when using the Rotterdam-Belgium corridor	120	km	
Battery capacity	150	kWh	Assumption explain in 5.3.1
Energy delivered to the drivetrain power electronics	1.1	kWh/km	
Pantograph cost	var	€/HGV	See Figure 5.7 Fout! Verwijzingsbron niet gevonden.
Maintenance cost (only pantograph)	1%	of the investment cost	
Grid-to-powertrain efficiency (direct driving on ERS (includes losses in vehicle, pantograph and ERS lines)	85	%	
Grid-to-powertrain efficiency (when driving outside ERS corridor on energy charged from the ERS	80	%	
Percentage of time driving on ERS	80	%	

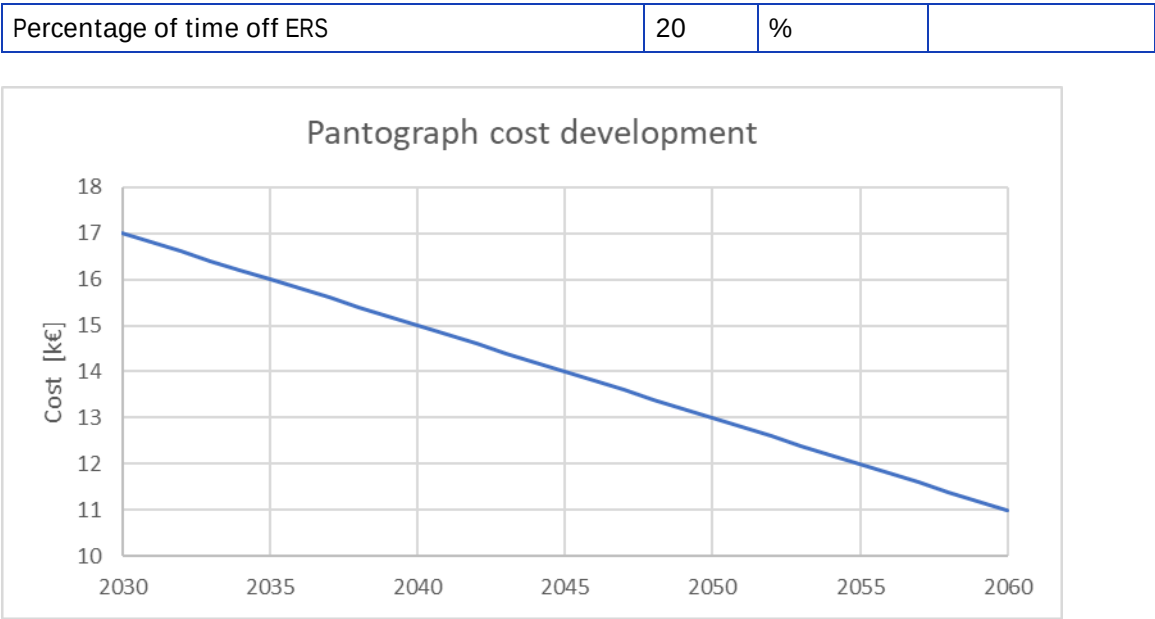


Figure 5.7: Pantograph cost development as used in the calculation.

5.4 Value of time

This section outlines the assumptions and inputs used to calculate the value of time, which is needed for assessing costs associated with the driver's waiting time during charging events at public stations.

The value of time for freight transport in the Netherlands is set at 63.1 €/hour, following the methodology of Significance (2023).

This value is applied when accounting for the driver's waiting time during charging events at public stations, specifically using MCS. The recharging time is calculated based on the time required to recharge the BEV battery and the total number of recharging events in the year.

Considering that only 20% of the recharging events will occur at public stations, and that trucks will travel two trips per day towards Belgium (back and forth) and one trip per day on the corridor to Germany, the number of recharging events per year is calculated based on the length of the corridor, the range of the battery, the operational days in a year, and the expected amount of BEV's in the corridor. Moreover, for each charging event, we assume a full battery charge. We did not account for the overlap of resting time and charging time.

Unlike BEVs, O-BEVs do not incur recharging time costs because they charge dynamically while driving on the ERS. This continuous charging capability means that O-BEVs are not subject to the downtime associated with stationary charging.

6 Scenarios

For both corridors separately two different scenarios were analysed, namely:

- 1) Only BEVs recharging at stationary chargers
- 2) A mix of O-BEVs on the ERS and BEVs recharging at stationary chargers.

The comparison between ERS and stationary charging is relevant given that electrification is proving to be the dominant route in the transition towards a sustainable road freight sector. By 2030, BEVs are expected to be a technically viable alternative for the vast majority of daily trips with HGVs and to have a Total Cost of Ownership (TCO) advantage over diesel trucks (TNO, 2022). As this transition unfolds, it is essential to assess whether ERS can offer additional benefits compared to electrification based on stationary charging.

Numerous studies (Börjesson et al., 2021; Decisio, 2022; Morfeldt et al., 2022; Rogstadius et al., 2023) have compared alternative powertrains such as BEVs, FCEVs and O-BEVs with ICE vehicles and have consistently shown the advantages of BEVs and O-BEVs over the other vehicle types in terms of energy consumption, emissions and TCO.

By focusing on both stationary charging and ERS systems, we aim to identify how possible cost savings for ERS compared to BEVs, associated with less recharging time, less need for depot chargers, and lower vehicle cost and space use, compare to the investment in ERS infrastructure.

The time frame of the scenario assessment is 2030-2060 (30 years). The ERS infrastructure construction is assumed to be finished in 2030. In this research, two corridors are taken into account, the characteristics of which are explained in Chapter **Fout! Verwijzingsbron niet gevonden..** For both corridors separately, the 2 scenarios are developed and comparatively assessed.

6.1 Projection for the overall HGV fleet on the corridors

In both scenarios, the future traffic follows the growth trends in goods demand that are also used for national inventories in the Netherlands (see Chapter **Fout! Verwijzingsbron niet gevonden.** for details). Such traffic is performed by a certain amount of trucks, assuming that in Corridor 1 toward Germany, one truck travels along the whole corridor once a day, while in Corridor 2 toward Belgium, one truck travels along the whole corridor twice a day (back and forth). Figure 6.1 shows the fleet size needed to carry out the predicted traffic according to the previous assumption.

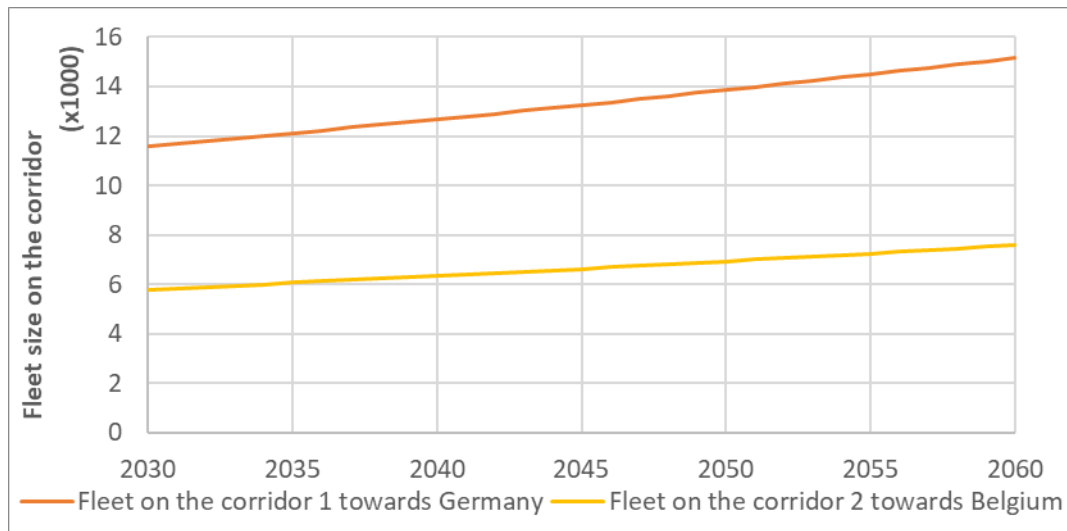


Figure 6.1: Projections for the average number of trucks on the corridors.

6.2 Scenarios for the shares of BEVs and O-BEVs on the corridors

Regarding zero-emission trucks, PBL (2024) predicts that, up to 2030, their market share in new sales will increase relatively quickly, but the share in the total vehicle fleet will remain modest. After 2030, this share will increase rapidly as a result of the European CO₂ standards for new HD road vehicles. Based on this, the assumed development of the fleet share for zero-emission vehicles on the corridor is consistent across both scenarios and both corridors. The share of zero-emission trucks is assumed to increase linearly from 3% in 2030 to 85% in 2060. The difference between Scenarios 1 and 2 lies in the assumed shares that BEVs and O-BEVs have in the overall share of zero-emission trucks on the corridor, as shown in Figure 6.2.

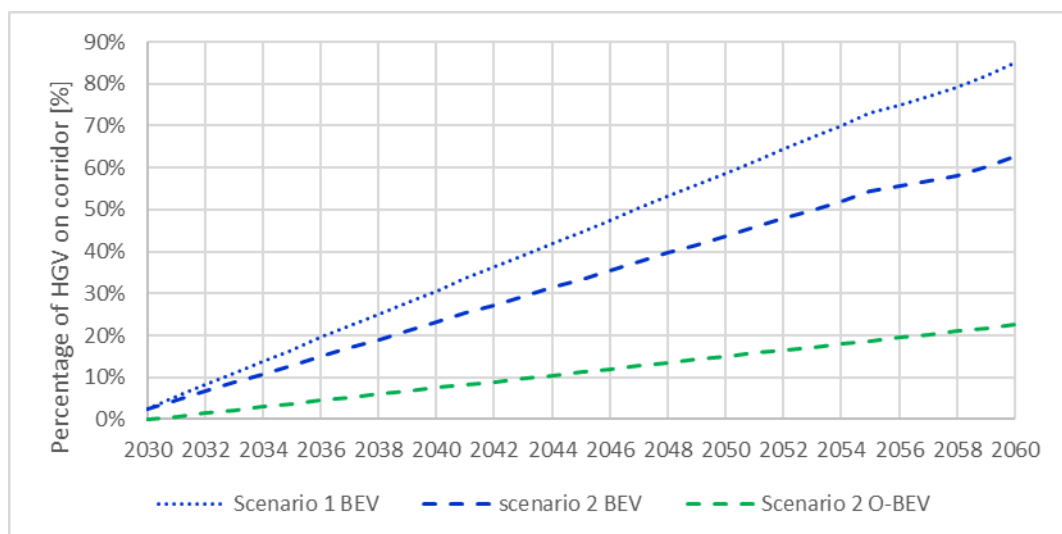


Figure 6.2: Assumed shares of Zero Emission HGVs (BEVs and O-BEVs) on the corridors as a percentage of the total amount of HGVs on the corridors for both scenarios.

As part of the social CBA, we compare the costs in Scenario 1 with those in Scenario 2. The result of subtracting the cost of Scenario 2 from the cost of Scenario 1 shows the net additional benefit or cost for society that the ERS system, modelled on the corridor, has overusing only static charging. For the fleet operators' business case, we also evaluate both scenarios to identify which is more advantageous for their operations.

In the case of the CBA for the ERS operator, we assess both the costs and revenues from operation within the second scenario. This comparison will allow us to see whether, or at what electricity sales price, the ERS operator's business case is sustainable and profitable.

6.2.1 Scenario 1: Stationary charging only

In this scenario, the total truck fleet consists of both ICEVs and BEVs, with the share of BEVs increasing gradually over time. Specifically, it is assumed that 3% of the truck fleet will be electrified by 2030, growing to 85% by 2060. The uptake of BEVs between 2030 and 2060 is modelled as a linear increase (see Figure 6.2).

For overnight charging, each truck is assumed to require a dedicated 50 kW charger.

6.2.2 Scenario 2: Stationary charging and ERS

This scenario contains the implementation of an ERS infrastructure in addition to a static charging infrastructure for those vehicles not using ERS. It is assumed that the infrastructure will be fully built and operational by 2030. Separate calculations were conducted for two corridors: Corridor 1 and Corridor 2 (see Chapter 4).

The uptake of zero-emission vehicles in Scenario 2 follows the same growth trajectory as in Scenario 1. However, the composition of the BEV fleet will change, as a growing share of O-BEVs operates on the corridor where the ERS is implemented (see Figure 6.2).

7 Results

In this chapter, we present the results of the Social CBA comparing the two scenarios. Additionally, we outline the outcomes of the CBA from the perspectives of both the ERS operator and the logistics operators. We further analyse how the key assumptions impact the CBA results, by means of a number of sensitivity analyses, offering insights into their influence on the economic viability of ERS compared to electrification with static charging only.

7.1 Social Cost Benefit Analysis (SCBA) of ERS

Table 7.1 shows the initial investment for the ERS infrastructure and the overall cost differential over the period 2030-2060 between the scenarios without and with ERS (= Scenario 1 – Scenario 2, meaning that a positive outcome represents a net (societal) benefit associated with implementing ERS) for the two corridors, based on the SCBA. With the assumptions described in the previous chapters, the SCBA shows a net cost saving for the scenario with ERS compared to the scenario based on 100% static charging.

Table 7.1: Summary of the result of the Social Cost Benefit Analysis (SCBA) comparing scenarios without and with ERS (Scenario 1 – Scenario 2).

Corridor	Initial investment	ERS length	Discount rate	SCBA NPV cost difference
Rotterdam - Germany	590 M€	180 km	3%	166 M€
Rotterdam -Belgium	239 M€	72 km	3%	126 M€

The difference between the cumulative NPV of the costs for scenarios 1 and 2 turns positive after 25 years for the corridor toward Germany, while for the corridor towards Belgium, it turns positive after 22 years, as seen in Figure 7.1 and Figure 7.2. This means that for both corridors and based on all cost inputs and assumptions used in this study, the investment in ERS and the trucks making use of it yields a net societal benefit over the 2030-2060 period.

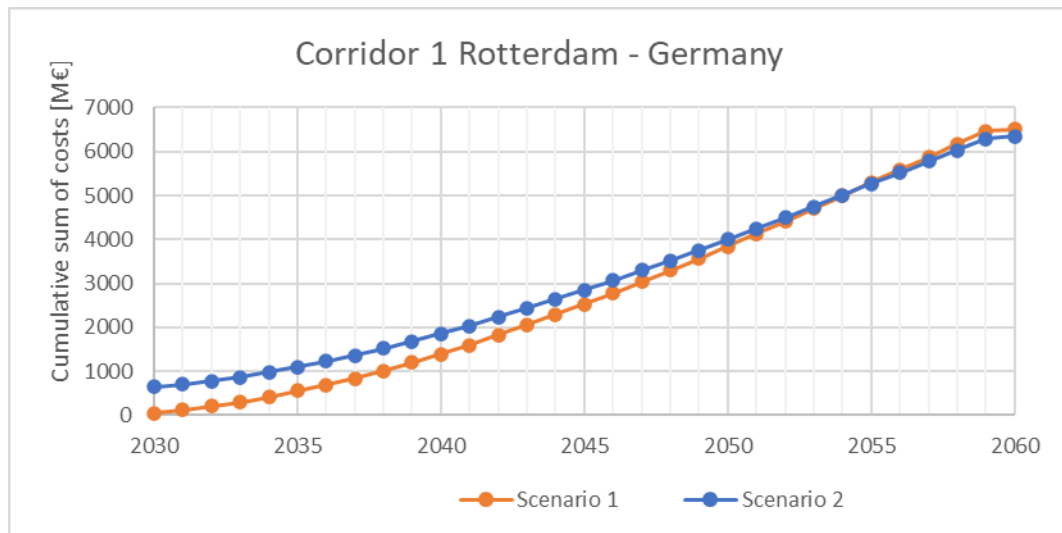


Figure 7.1: The graph shows the cumulative sum of the discounted costs for the scenarios with and without ERS, based on the SCBA for Corridor 1.

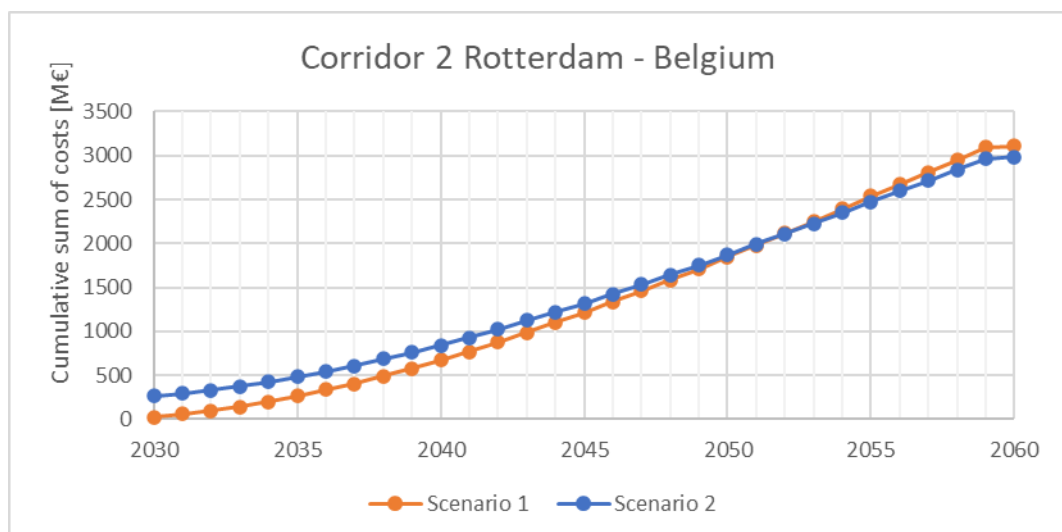


Figure 7.2: The graph shows the cumulative sum of the discounted cost for the scenarios with and without ERS, based on the SCBA for Corridor 2.

It is important to note that this outcome is quite sensitive to variations in key cost factors and assumptions. Therefore, in Section 0, we check the influence of those variations on the outcomes in a number of sensitivity analyses.

7.2 Business case for ERS operator and logistic operators

For our calculations, we assume a fixed energy price for the ERS users over the entire 2030-2060 period. In reality, however, this price may vary based on e.g. price strategies chosen by the ERS operator, possible subsidies from the government and developments in the utilization of the infrastructure.

While higher prices at low utilization could help achieve quicker system payback for the ERS operator, it could discourage logistic companies from purchasing ERS-compatible trucks, and would thus reduce overall system use. The pricing of electricity drawn from the ERS system thus influences the likeliness of achieving a significant uptake of O-BEVs. In our CBAs from the end user and ERS operator perspectives we therefore use a range of electricity prices.

The result of the CBA for the business case of the operator of the ERS is shown in Table 7.2. For electricity prices that are in the range of the prices expected for fast charging (€0.4 - €0.5 per kWh) the business case for the ERS operator is negative. For the business case to be viable, the energy price for the end-user on the ERS would need to be above €1 per kWh, averaged over the total 2030-2060 time period. In this assessment it is assumed that the ERS operator is a public entity. For that reason the CBA is carried out using a discount rate of 3%. If the ERS system would be implemented and operated by a private party, the higher discount rate (9.5% in this study) would make the business case even less profitable, leading to a break-even electricity price way higher than €1.2 per kWh.

Table 7.2: Net Present Value of revenues minus costs for the public ERS Operator over the 30 year period of operation for different energy prices charged to end users.

Cost of charging on ERS [€/kWh]	NPV Corridor 1 [M€]	NPV Corridor 2 [M€]
0.2	-695	-285
0.3	-624	-251
0.4	-552	-217
0.5	-481	-183
0.6	-409	-148
0.7	-337	-114
0.8	-266	-80
0.9	-194	-46
1.0	-122	-12
1.1	-51	22
1.2	21	56

The result of the CBA for the business case of the end user of the ERS (logistic operator) is shown in Table 7.3. For electricity prices that are in the range of the prices expected for fast charging (€0.4 - €0.5 per kWh) the business case for the end user is positive. Only if the cost of charging at the ERS exceeds €0.7 per kWh, the financial incentive for fleet operators to adopt ERS become negligible or even negative, meaning that the business case for using ERS becomes economically unviable. In that case the cost advantages associated with cheaper trucks and less waiting time for charging are more than compensated high energy costs during operation.

Table 7.3: The cost differential between the scenarios without and with ERS (Scenario 1 – Scenario 2) for the end users in logistic sector over the 30 year period of operation on the ERS for different energy prices on the ERS.

Cost of charging on ERS [€]	NPV Corridor 1 [M€]	NPV Corridor 2 [M€]
0.2	370	176
0.3	298	142
0.4	226	108
0.5	155	74
0.6	83	39
0.7	11	5
0.8	-60	-29
0.9	-132	-63
1.0	-204	-97
1.1	-275	-131
1.2	-347	-165

Although ERS yields net benefits from a societal perspective, given the inputs and assumptions used in our study, comparing the CBA results for ERS operators and end users shows that there is no range for the price of electricity consumed on the ERS for which the business case is positive for both stakeholders in the value chain. At prices that are of the same order as for static fast charging the implementation of ERS is attractive to end-users but not economically viable for public ERS operators, let alone for operators from the private sector.

The tipping points for ERS to become attractive to end-users and infrastructure operators respectively obviously depend on the cost inputs and assumptions used in the CBA. The impact of varying some of these cost inputs and assumptions is explored by means of sensitivity analyses.

7.3 Sensitivity analyses

In this section, we examine the influence of key factors such as infrastructure and battery costs, utilization, and vehicle energy consumption on the outcomes of the analysis. By assessing the influence of these key parameters, we aim to understand the robustness of conclusions from the CBA on the societal and economic viability of the analysed ERS corridors. This will help us identify critical assumptions that could affect the success of the system and could therefore deserve further scrutiny.

7.3.1 ERS system construction costs

The investment costs to build the ERS play a significant role in the outcome of the SCBA. The ERS investment costs found in the literature vary between €1.2 million and €4.6 million per kilometre as shown in Table 7.4.

Table 7.4: Overview of various estimates of investment costs to build ERS.

Parameter	Value min	Value max	Source
CAPEX Investment cost two-way (M€/km)	3.10	3.30	Movares (2020); Decisio (2022); Bakker et al. (2023)
	1.2	4.6	Kühn et al. (2017)
	2.30	2.80	Aronietis and Vanelslander (2023)
	1.40	2.34	Ainalis et al. (2022); den Boer et al. (2013); Deshpande et al. (2023)
	1.70	-	Fraunhofer Institute et al. (2018) Sundelin et al. (2018)
	2.50	-	Boston Consulting Group and Prognose (2019); Börjesson et al. (2021)

The impact of varying the investment costs on the SCBA outcome for the two corridors in the study is shown in Table 7.5.

Table 7.5: Outcome of the SCBA for the difference in the cumulative NPV of costs for the scenarios without and with ERS (Scenario 1 – Scenario 2), depending on the ERS building cost.

ERS cost [M€/km]	Corridor 1 NPV [M€]	Corridor 2 NPV [M€]
1.0	648	322
1.5	542	280
2.0	437	237
2.5	331	195
3.0	225	153
3.28	166	126
3.5	119	110
4.0	14	68
4.5	-92	26
5.0	-198	-17

With all other inputs and assumptions remaining the same, a positive SCBA result for the ERS system, i.e. that the scenario with ESR has a net benefit compared to the scenario based on static charging only, can be achieved if the ERS implementation costs remain below €4 million per kilometre. This underscores the importance of keeping the implementation costs under constant review to ensure economic viability.

7.3.2 Battery price

To check the influence of battery price on the outcome of the SCBA, we looked at the 4 scenarios shown in the study (Link et al., 2024) and we added the study Mauler et al. (2021) as the most optimistic price scenario. We can see in Table 7.6 that the selection of the most probable battery price scenario is very crucial for the CBA.

Table 7.6: The outcome of the SCBA for the difference in the cumulative NPV of costs the scenarios without and with ERS (Scenario 1 – Scenario 2) is strongly dependent on the battery price development (See Section 5.3.1 for details).

Battery price scenario	Corridor 1 NPV [M€]	Corridor 2 NPV [M€]
Mauler et al. (2021)	-6	40
Near Market	25	55
Average All (Base)	166	126
Scientific	188	137
Other	231	158

If battery prices decrease faster than in the base assumption used for the main SCBA analysis, the benefits of ERS decline. For an average reduction of battery prices by over 30 €/kWh compared to the baseline scenario, the ERS will no longer be economically viable from a societal perspective compared to the 100% static charging option. Slow cost reduction rates, than assumed in the baseline scenario, obviously improve the economic viability of the ERS corridors.

The impact of varying battery prices on the fleet operator's CBA is less significant, as shown in Table 7.7. In this sensitivity analysis an electricity price on the ERS of €0.30 per kWh is assumed. This value was initially chosen, based on a comparison with expected cost of depot charging and static fast charging, as it makes sure that using ERS is profitable to end-users. In hindsight, given the results described in section 7.2, this value is unrealistically low. In this sensitivity analysis, however, that is not a problem as it does affect the absolute level of the cost differential between the scenarios but not its sensitivity to varying the costs of batteries.

Compared to the SCBA, the impact of varying battery costs is moderated by the fact that most battery expenditures occur later in the analysis period (specifically, in the second half of 2030–2060) as more O-BEV trucks are introduced. These later costs are more heavily discounted in the fleet operator's CBA than in the Social CBA. As a result, while varying battery prices could potentially have a strong influence on the fleet operator's CBA, the discounting effect on future costs ultimately diminishes their impact in this analysis over the entire 2030-2060 period.

Table 7.7: The cost differential between the scenarios without and with ERS (Scenario 1 – Scenario 2) for fleet operators (logistics sector), depending on the battery price development scenario.

Battery price scenario	Corridor 1 NPV [M€]	Corridor 2 NPV [M€]
Mauler et al. (2021)	229	107
Near Market	241	113
Average All (Base)	298	142
Scientific	307	146
Other	324	154

7.3.3 Battery size

When considering the influence of battery size, we can see that the bigger the difference in battery size between BEVs and O-BEVs the more viable the ERS option becomes. As can be seen in Table 7.8 and Table 7.9 the tipping point from a societal point of view is roughly at 300 kWh difference between the battery sizes of BEVs and O-BEVs.

Table 7.8: Impact of the selection of battery sizes for BEVs and O-BEVs on the outcome of the SCBA for the difference in the cumulative NPV of costs for scenarios without and with ERS (Scenario 1 – Scenario 2) for corridor 1 (Rotterdam – Germany).

Corridor 1		O-BEV battery size [kWh]						
NPV [M€]		75	100	150	200	300	400	500
BEV battery size [kWh]	400	4	-15	-51	-88	-161	-234	-307
	500	70	52	15	-21	-94	-167	-240
	600	143	125	89	52	-21	-94	-167
	700	221	203	166	130	57	-16	-89
	800	301	283	247	210	137	64	-9
	900	384	365	329	292	219	146	73
	1000	467	449	412	375	302	229	156
	1100	551	533	496	460	387	314	241
	1200	636	617	581	544	471	398	325

Table 7.9: Impact of the selection of battery sizes for BEVs and O-BEVs on the outcome of the SCBA for the difference in the cumulative NPV of cost for scenarios without and with ERS (Scenario 1 – Scenario 2) for corridor 2 (Rotterdam – Belgium).

Corridor 2		O-BEV battery size [kWh]						
NPV [M€]		75	100	150	200	300	400	500
BEV battery size [kWh]	400	31	21	3	-15	-52	-88	-125
	500	70	61	43	25	-12	-48	-85
	600	111	102	84	66	29	-7	-44
	700	153	144	126	108	71	35	-2
	800	196	187	169	150	114	77	41
	900	239	230	211	193	157	120	84
	1000	282	273	254	236	200	163	127
	1100	325	316	298	279	243	206	170
1200	368	359	341	323	286	250	213	

It can be seen that the difference between the battery sizes of BEVs and O-BEVs is a very influential factor in the result of the CBA. Should logistic operators refrain from reducing the battery size of their ERS trucks, then the ERS option will be more expensive than the stationary charging option.

7.3.4 O-BEV uptake scenario

We also explored the impact of different levels of O-BEV adoption on the CBA, as depicted in Figure 7.3. The uptake variants in this sensitivity analysis are as follows:

- Very low: 50% of the main scenario,
- Low: 75% of the main scenario,
- Main scenario, and
- High: 125% of the main scenario.

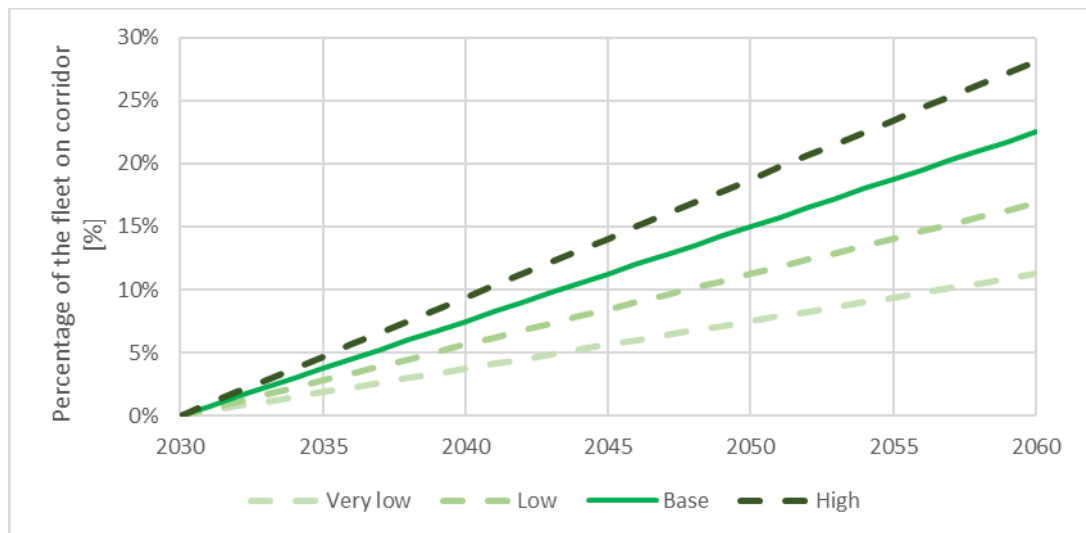


Figure 7.3: Variations in the uptake options for O-BEV, as share of the total HGV fleet on the corridor, used in a sensitivity analysis.

The viability of ERS obviously depends on the utilisation rate of the system. Varying the share of O-BEVs in the HGV fleet on the corridor will thus have a strong influence on the result of SCBA. If the O-BEV uptake is around 25% lower than in our baseline scenario, the BEV-only scenario would be slightly better for society for the case of the Rotterdam – Germany corridor, as can be seen from the green line in Figure 7.4.

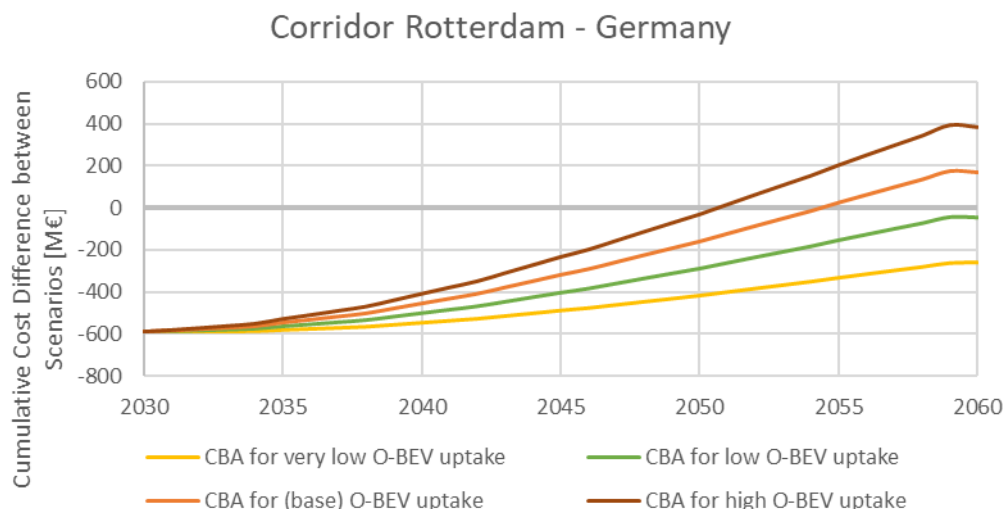


Figure 7.4: The Social CBA outcome for the difference between the cumulative NPV of the costs for the BEV only scenario and the O-BEV scenario for ERS corridor 1 Rotterdam-Germany with 4 different O-BEV truck uptake scenarios (Very low = 50% of uptake in the base scenario, Low = 75% of uptake in the base scenario, Base scenario, and High = 125% of uptake in the base scenario). Details of the base uptake scenarios are described in Chapter 6.

In the case of corridor 2 (Rotterdam – Belgium), for a 25% lower O-BEV uptake (green line in Figure 7.5 the costs from a societal perspective of the two scenarios can be considered almost equal.

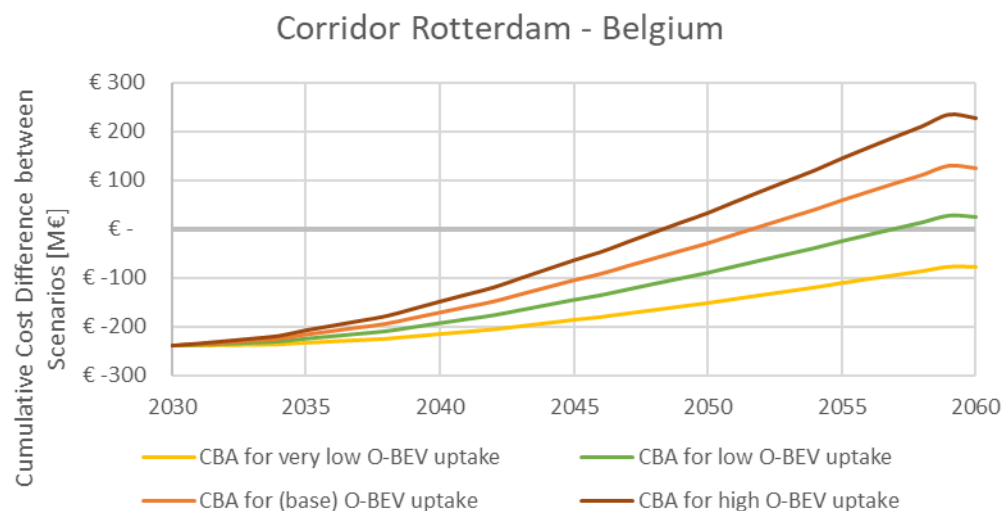


Figure 7.5: The Social CBA outcome for the difference between the cumulative NPV of the costs for the BEV only scenario and the O-BEV scenario for ERS corridor 2 Rotterdam-Belgium, with 4 different O-BEV truck uptake scenarios (Very low = 50% of uptake in the base scenario, Low = 75% of uptake in the base scenario, Base scenario, and High = 125% of uptake in the base scenario). Details of the base uptake scenarios are described in Chapter 6.

7.3.5 Depot and public charging share

Another significant element in the analysis of the SCBA is the ratio of depot charging to public charging for BEVs. It is assumed that companies will charge as much as possible at the depot, given that the corridors in question are very short and the majority of journeys can be made during the day. Depot charging is cheaper than fast charging at public charging facilities on the corridor. If the companies were to fully charge only at the depot and were to refrain from utilising the MCS infrastructure, the societal benefits of ERS scenario are expected to reduce. Alternatively, should the companies need to make use of MCS charging more than assumed in the baseline, then the societal benefits will increase. Table 7.10 shows that, if the share of MCS charging constitutes 10% or more, a more beneficial course of action from a societal perspective would be to transition to O-BEVs and use ERS. Obviously this result is sensitive to the assumed price of electricity charged at MCS facilities (see section 5.2).

Table 7.10: The Social CBA outcome for the difference between the cumulative NPV of the costs for the BEV only scenario and the O-BEV scenario for different shares of depot charging and MCS charging of BEVs.

Share of depot charging to public MCS	Corridor 1 [Value M€]	Corridor 2 [Value M€]
0% / 100%	1114	508
10% / 90%	995	460
20% / 80%	877	413
30% / 70%	758	365
40% / 60%	640	317
50% / 50%	522	269
60% / 40%	403	222
70% / 30%	285	174
80% / 20%	166	126
90% / 10%	48	78
100% / 0%	-70	30

8 Discussion

Below we address several issues and considerations that have shown to be of importance for the evaluation of ERS, but could not be given full consideration due to the limited budget and timespan of the study.

- Factors affecting ERS construction costs and potential cost-saving strategies

Our analysis indicates that ERS could be financially viable from a societal perspective, even with a limited-length corridor, if the construction cost is 3.5 million euros per kilometre or less. In the sensitivity analyses, we show that the impact of varying the cost of the ERS build per km on the economic viability is significant. With around 25% higher construction costs, the benefits over static charging become negligible for the assessed corridors. Many factors influence ERS costs, as highlighted in studies such as Movares (2020), Kühn et al. (2017), and Rogstadius et al. (2022).

Grid connection uncertainties are one of the key elements in this context. The distance to medium- or high-voltage grid networks is an important factor. The greater the distance, the more complex and costly it becomes to connect the ERS system to the grid. Issues related to existing infrastructure, land availability, and obtaining necessary permissions are more likely to arise over longer distances, all of which can increase costs. Additionally, the power requirements and any necessary infrastructure modifications can further impact the connection process and costs. Movares (2020) shows that choosing between one big connection for several inverters with an internal power grid and a separate connection for each point inverter will influence the buildup cost.

Maximizing the synergy between ERS buildup expenses and charging infrastructure investments along the corridor would be a way to optimize the use of resources (such as grid connections), reduce costs, and improve efficiency, benefiting both systems.

- Number of users / O-BEV uptake

Our assumption on the uptake of O-BEVs over time, determining the number of users of the ERS infrastructure, reaching just above 20% of the fleet on the corridors by 2060, may be considered very conservative. However, even with that conservative assumption and the consequent utilisation rate of the ERS the SCBA shows a fairly robust positive outcome for ERS. With the capacity of the ERS infrastructure, assumed in our analysis, a higher utilisation will merely increase the societal benefit up to the point where additional capacity needs to be implemented to meet the energy demand of an increase share of O-BEVs in the fleet.

In discussions with logistic operators during the ERS Community Day organised by IenW on 24 June, we saw interest in using ERS from companies that are not in a position to build sufficient charging infrastructure at their depot, and also from companies whose trucks do not always return to the depot for the night. These companies face the additional challenge of finding charging infrastructure and the ERS is an interesting solution for them. These types of companies are considering the use of ERS on shorter routes between their depot or around the port of Rotterdam. This shows that there may be additional interest in ERS that is not currently considered in this report. This additional interest could even translate into increased willingness to pay in terms of acceptable electricity prices on the ERS. We are now

assuming that using ERS needs to be cheaper for logistic operators to make it an attractive alternative for static charging, but if the latter is no option for them, they may also want to use ERS if it is more expensive than static charging.

- Battery price

Under our current assumptions for the development of battery prices, the SCBA outcome is positive for ERS, but it is highly sensitive to any changes in the assumed battery price development. The aspect of battery price development is of importance for the whole energy transition, not only within the transport sector, has a significant impact, and there is much speculation regarding future costs. Currently, we observe a trend of rapidly decreasing prices, with some estimates predicting prices will drop below 50 euros per kWh by 2030¹³. However, events like the COVID-19 pandemic and the war in Ukraine caused a temporary increase in the prices in 2022 and 2023 which was not expected in studies like Mauler et al. (2021). Constant developments in battery technology bring breakthroughs, such as improvements in LFP (Lithium Iron Phosphate) batteries, while other areas, like solid-state batteries, have seen slower progress. These mixed advancements make price predictions highly challenging.

Another important factor in the discussion on the influence of battery price on the SCBA of ERS is timing. The longer the ERS deployment is delayed, the more static charging infrastructure will likely be established and the lower the battery prices will be. This will eventually reduce the benefits of ERS compared to static charging. Therefore, timing is a significant factor in the overall success of the ERS implementation.

- Wider aspects related to battery size

The implementation of ERS provides a significant opportunity for truck operators to reduce the size of the batteries required in their vehicles, which reduces initial costs and curbs the weight of the truck. This benefit is considered an important motive to purchase O-BEVs for their operations. Recent work in the UK suggests that trucks with heavy batteries could result in an increased number of truck-kilometres in the system, along with higher costs of trade. The first numbers mentioned suggested capacity reductions of 20%, which would imply a substantial new burden for the road freight market (source: discussion with prof. David Cebon, September 2024). As these preliminary numbers on weight seem very relevant, we recommend that this effect is further examined and included in later studies.

Reducing battery size also has a broader societal impact, as it can reduce dependence on critical raw materials¹⁴ such as lithium, cobalt and nickel, which are essential components of battery packs. By reducing the demand for these materials, the EU can reduce its dependence on countries that supply these materials, potentially reducing supply chain risks and geopolitical dependencies.

Whether truck operators choose O-BEVs with small batteries largely depends on the extent to which the ERS network overlaps with their logistic network, but also on the perceived risk of relying too heavily on limited ERS corridor operators (Decisio 2022, Beker 2023 and PARIC 2023). With smaller batteries, companies would become increasingly dependent on the accessibility and coverage of the ERS network to meet their operational requirements. This is especially challenging when only a single corridor is available instead of a more widespread system.

¹³ [Batteries: how cheap can they get? - by Auke Hoekstra](#)

¹⁴ [European Critical Raw Materials Act - European Commission \(europa.eu\)](#)

The availability of trucks with smaller or modular batteries will be a key factor in battery size reduction. Companies will only be able to choose trucks with smaller batteries if OEMs provide them as an option. Otherwise, they will have to opt for larger batteries, which will significantly reduce the initial O-BEV purchase benefits.

To ensure that the benefits of battery size reduction are fully realised, a long-term commitment to the development of ERS infrastructure would be beneficial. A comprehensive, Europe-wide plan that includes all charging solutions and consistent policy support, investment in infrastructure and coordination between the various stakeholders (including between countries) would provide more support for truck OEMs to develop suitable products and for trucking companies to make informed decisions on battery size.

- Effect on battery lifetime

In our study, we did not account for the effects of depot, MCS, or ERS charging on battery lifespan. However, studies such as Al-Saadi et al. (2022) suggest that smaller batteries, when slow-charged, may have longer lifespans (in terms of the available number of charge-discharge cycles) due to improved thermal management and better cycling performance. The benefits seem to be small, compared to the other effects (Liao et al., 2024). In addition the number of charge-discharge cycles per unit of truck operation may be different for BEVs and O-BEVs. The use of ERS may allow the batteries of O-BEVs to undergo fewer charging cycles compared to BEVs with stationary charging, but this depends on how trucking companies integrate O-BEVs into their operations and the overall extent of the ERS network. Nevertheless, in a full CBA, these effects should be considered.

- Effect of reduced deployment flexibility of trucks

The flexibility of deployment is different for diesel, battery electric and ERS trucks. The effect of reduced flexibility for ERS trucks was not explored in this study, but it is likely to depend heavily on the size of the ERS network, especially when O-BEVs are equipped with small batteries and would only use the ERS infrastructure for charging. Decisio (2022) stated that only heavy goods vehicles (HGVs) that regularly travel on the ERS network would likely benefit from the system, which would limit the number of potential users. LMS data shows a high number of trips using the selected corridors, but uncertainties about trip start and end locations, and the kilometres driven on the corridors, which are influenced by the origins and destinations of the shipments and the business locations of the ‘carriers’ (logistics service providers), make it difficult to draw conclusions, especially when looking at a single corridor. We highly recommend a more detailed assessment of the usage patterns of HGVs that travel on the corridors in order to arrive at a well-substantiated estimate of the amount of HGVs that would be suitable for replacement by O-BEVs using the ERS and the extent to which the size of the batteries of these vehicle can be reduced compared to normal BEVs. A more detailed analysis of the BasGoed and LMS data, as suggested by Bakker et al. (2023), could already provide better insights into potential users. Also here, however, strong assumptions may be needed about how companies will manage their future fleets and their charging solutions.

- Effects on electricity network congestion

Static charging, with a mix of private depot charging and public fast charging, and ERS lead to significantly different load patterns for the electricity grid. The effect on the electric grid was not included in the CBA as the exact impact could not be determined nor monetized in the framework of this short study. During the project, we discussed with different specialists in the field. This consultation has led to a number of insights and related expectations about the potential effects of ERS for the relief of grid congestion.

Firstly, dynamic charging offers the ability to adjust charging power based on real-time network conditions. When a truck drives under the ERS overhead line, charging power can be modified in response to energy network congestion, allowing for a dynamic load management system. To enable this, trucks must be equipped with electrical systems that include a power reserve and sufficient battery capacity, as well as communication capabilities to interact with the ERS. This setup allows the ERS to request a temporary reduction in the truck's energy consumption if needed to ease grid load. If the truck cannot reduce its consumption, specific ERS segments can be powered down to lower the grid impact, allowing the truck to switch to battery power until the next ERS section.

Secondly, charging station operators may face uncertainty regarding whether to stay with CCS HPC (High Power Charging) or to invest in Megawatt Charging Systems (MCS), which may require high-power grid connections. A key concern here is that these megawatt-scale power connections may face periods of low utilization, resulting in operational inefficiencies and increased economic costs. In response, many investors may opt for lower-capacity connections. This in turn may result in longer waiting times for charging spots and extended charging times for logistic operators, particularly during peak demand hours. The potential delays caused by waiting and charging times have been factored into our analysis to first order, and have been monetized using the Value of Time for logistic operators. A more detailed analysis of this impact, including dependence on the type of chargers chosen and the availability of chargers, could be made in a future study. In this context, ERS can be seen as complementing the existing charging infrastructure. It will reduce reliance on stationary chargers, which may relieve charging needs during peak hours. This could lead to reduced waiting times at the charger and reduce the need for grid reinforcements due to reduced peak demand.

Thirdly, it can be expected that energy consumption of charging stations would peak around driver's break periods, while ERS trucks would charge more evenly throughout the day. Thus ERS could help balance the energy load over time, making grid usage more efficient. This could also reduce the need for high-capacity peak-time grid connections. Gaete-Morales et al. (2023) show that the ERS could alleviate grid demand in times of high grid load in particular if vehicle-to-grid capabilities are realized, where trucks can discharge on the network, postpone charging their battery from the overhead wires or drive on their battery while under the overhead wires.

Finally, we note that any charging solution will require upgrades to the electric grid. This is necessary to bring energy supply to highways and major road networks, ensuring compliance with the AFIR. This means that, ideally, the effects of ERS should be studied within this context. Given the AFIR requirements for static charging infrastructure, in the short to medium term ERS should be regarded as additionally needed investments. In the long term, the widespread availability of ERS may reduce the demand for stationary charging infrastructure (Rogstadius, 2022). If this reduction is taken into account during the early stages of planning for both charging and ERS infrastructure, it could lead to a decrease in the need for subsidies for infrastructure, which may not be fully utilized in the future.

- Safety

The implementation of ERS involves overhead wiring systems that could prevent, for example, emergency service helicopters from landing directly on electrified road sections. Landing a helicopter on a six-lane highway with ERS is impossible due to size restrictions, and even on eight-lane ERS highways, it remains highly debatable due to wind effects on the catenary system (Grosse et al., 2022). Additionally, overhead wires restrict the use of lifting equipment like truck recovery cranes. These factors impose the need for alternative

solutions for emergency response and vehicle recovery to ensure smooth operations and safety on the highway. As highlighted in Decisio (2022), designated roadside landing areas at regular intervals could serve as viable alternatives. Moreover, German studies (Grosse et al., 2022) emphasize the importance of planning these alternative landing zones to maintain emergency response effectiveness.

- Impact on driving behaviour

According to Decisio (2022), the impact of ERS on the landscape can vary significantly depending on the location. The introduction of overhead wires might change driver behaviour, with some drivers potentially avoiding lanes directly under the wires. This could lead to increased traffic in other lanes, as drivers may prefer not to drive beneath the catenary system. This behavioural shift is not accounted for in the current SCBA. However, similar driver behaviour has been observed in existing conditions where drivers often avoid the first lane due to heavy-goods vehicle traffic (Chatterjee et al., 2016). Therefore, while this effect might not significantly alter the overall traffic dynamics, it is an important consideration for the practical implementation of ERS systems.

- Impact on landscape

Overhead wires visually impact the landscape. (Decisio, 2022) suggests that this can be minimized by taking into account the natural environment and existing road usage patterns to minimize visual impacts and drivers' behavioural disruptions (avoidance to drive under overhead wires).

- CO₂ emissions reduction and electricity mix

Despite the fact that, on a Tank-to-Wheel basis, trucks that use ERS and stationary charging offer similar CO₂ reduction benefits, the outcomes may be different on a Well-To-Wheel basis in the short to medium term as long as electricity production is not fully renewable. Day- and nighttime charging, and peak and off-peak charging all use a different mix of renewable and non-renewable sources. We have not included this consideration in the SCBA but it is recommended to carry out a broader life-cycle analysis where the carbon content of different electricity sources, direct energy consumption, bypassing the losses in battery, the impact of battery production and the usage of energy during daytime is taken into account.

As electricity production is planned to decarbonise faster than other sectors, this effect will be eliminated in the longer term. The different energy demand patterns, resulting from static and dynamic charging, however, need to be taken into account in the design of the overall, sustainable electricity supply system, as it will affect the amount of controllable power and storage that may be needed to match overall demand and supply.

- Environmental impacts of pantograph systems

Decisio (2022) suggests that the greatest negative environmental impact of ERS is caused by the abrasion of the contact wire (copper) and the pantograph slipper (carbon). Decisio has calculated that over the entire lifetime of the ERS, which is estimated to be 35 years in their study, approximately 1,000 kg of abraded copper per kilometre will end up on the road and in the surrounding environment. This amount of copper loss highlights an environmental concern associated with the implementation of ERS and the need to better understand the effect in real life. It is argued that scarcity and losses of copper due to ERS infrastructure might also impact the price and availability of this material. As the foundation for these concerns is still weak, they were not included in the CBA.

- Effect on the road surface

In the SCBA we do not consider potential impacts on road surface wear. This might reduce in a scenario with ERS due to lighter trucks as a result of reduced battery weight. On the other hand road surface wear may increase due to the rutting effect caused by trucks driving under the ERS wires. Studies such as Gou et al. (2022) show that safety systems such as the Emergency Lane Keeping System (ELKS), which will become mandatory from 7 July 2024¹⁵ and automated driving will have a similar effect as also these technologies will cause trucks to be centred in the driving lane. Therefore, probably, the addition of ERS infrastructure will not have any additional negative impact in this sense.

¹⁵ [General Safety Regulation \(EU\) 2019/2144](#)

9 Conclusions

For two road freight corridors, this study evaluated the costs and benefits of the addition of ERS infrastructure to a baseline characterised by increased uptake of battery-electric trucks: Corridor 1 from the Port of Rotterdam towards Germany, and Corridor 2 from the Port of Rotterdam toward Belgium.

The main findings suggest that, under favourable conditions, investments in ERS can be societally cost-effective compared to relying solely on static charging for the electrification of the truck fleet. The primary sources of these benefits are lower upfront investments in trucks (due to smaller batteries of ERS trucks), reduced expenditures on static charging infrastructure, and minimized driver downtime. The CBA from the perspectives of ERS operators and ERS end users (logistics companies) shows a more complex result, as also illustrated in Table 9.1. In interpreting this, it first needs to be taken into account that the differences between the societal perspective and the business perspective are strongly influenced by the discount rates used for both cases (3% vs. 9.5%). Cost and benefits occurring later in the period 2030-2060, during which the ERS is assumed to be in operation, have a higher value in the societal perspective than in the business perspective. In our assessment it is assumed that the organisation operating the ERS is a public entity, while obviously the end users are private companies (fleet operators).

Table 9.1: Overview of the outcomes: potential cost savings of the scenario with ERS compared to the static charging only scenario resulting from the cost-benefit analyses carried out from a societal (SCBA), end-user (fleet operator / logistic service provider) and ERS operator perspective. The fleet operator and ERS operator perspectives show a bandwidth of outcomes based on an energy price on the ERS between €0.20 and €1.20.

Corridor	Initial investment [M€]	ERS Length [km]	Social CBA cost difference [M€]	Fleet operator CBA cost difference [M€]	ERS operator CBA [M€]
Rotterdam - Germany	590 M€	180	166	370-to -347	-695 to 21
Rotterdam - Belgium	239 M€	72	126	176 to -165	-285 to 56

Although ERS can yield net benefits from a societal perspective, given the inputs and assumptions used in our study, the business case for end-users and ERS operators depends strongly on the price of electricity for users of the ERS. At prices that are of the same order as for static fast charging the implementation of ERS is attractive to end-users but not economically viable for public ERS operators, let alone for operators from the private sector. Comparing the CBA results for ERS operators and end users for different values of the electricity price on the ERS shows that there is no range for the price of electricity consumed on the ERS for which the business case is positive for both stakeholders in the value chain. For ERS to be profitable for end users this price needs to remain below 0.70 – 0.80 €/kWh, while for ERS operators the price would need to be above 1.00 – 1.10 €/kWh to yield a profitable business case. To solve this, investment or exploitation subsidies to ERS operators could be used, effectively subsidizing the electricity price for ERS users. The tipping points for

ERS to become attractive to end-users and infrastructure operators respectively obviously depend on the cost inputs and assumptions used in the CBA.

The uptake of O-BEVs on the ERS corridor is a crucial factor and relates to the above mentioned issue with respect to the ERS electricity price. A business case favourable to fleet operators—driven by low energy prices on the ERS—could stimulate higher adoption of O-BEVs. However, offering low energy prices to fleet operators will compromise the financial viability of the ERS operator's business model.

Conversely, setting higher energy prices to enhance the ERS operator's profitability could make the system less attractive to fleet operators, thus reducing the number of O-BEVs on the corridor. A lower O-BEV uptake could jeopardize the positive social CBA outcome, limiting the ability of ERS to deliver its intended societal and environmental benefits effectively.

More generally, it must be emphasized that the outcomes of our analysis are accompanied by substantial uncertainties related to key factors, such as the investment costs per kilometre for ERS infrastructure, future battery price developments, choices made with respect to reductions in battery size, and the adoption rate of O-BEVs in the fleets using the corridors. Sensitivity analyses have been made which show that variations in some of the main cost drivers and assumptions have significant impacts on the outcome of the CBA, in the sense that they may tip the scale in the comparison of societal costs and profitability for end-users and ERS operators between a scenario with ERS and one with static charging of electric trucks only. In addition, various aspects have been identified that may affect the outcome of a (S)CBA but could not be assessed and quantified in the context of this study.

An important uncertainty is the share of vehicles on the corridor for which ERS is a technically feasible option, given their operational profiles in terms of logistic service and the associated distances travelled on and outside the corridor. Despite efforts made, this issue could not be assessed appropriately with limitations for this project determined by budget, time and data availability. We highly recommend a more detailed assessment of the usage patterns of HGVs that travel on the corridors in order to arrive at a well-substantiated estimate of the amount of HGVs that would be suitable for replacement by O-BEVs using the ERS and the extent to which the size of the batteries of these vehicle can be reduced compared to normal BEVs.

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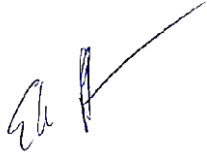
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Appendix A

ERS Cost per km
calculation

ERS cost calculation is based on Movares (2020) for the A15 highway and recalculated for Corridor 1 and Corridor 2.

					Movares	Corridor 1	Corridor 2
Category	Part	Comments	Unit	Price per unit	Cost [k€/km (2 directions)]		
Overhead lines	Direct building costs	Mast (every 30 m), foundation, wires	[€/m]	300	600	600	600
	Overall costs	Incl. risks, permits, land, design	[€/m]	450	900	900	900
	Reinforcement cables	Single cable along route	[€/m]	315	315	315	315
	connections between lines	every 500 m	[k€/pc]	42	84	84	84
Converter station	A total of 64 units along the A15	Incl. permit, deployment, foundations, etc.	[M€/pc]	1.3	687.6	664.4	686.1
	Optic fibre connection		[K€/pc]	100	53	51	53
Control and monitoring	Optical fibre		[€/m]	10	10	10	10
	Control center		[M€/pc]	2	16.5	11.1	25
Power supply	MS cable	Total 400 km (network operator)	[€/m]	152	502	502	502
	Connection 3500 kVA	for number of stations shown in the table	[k€/pc]	270	143	138	142.5
				Length of corridor (km)	121	180	72
				Number of Stations:	64	92	38

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