Cost-effectiveness analysis Electric Road Systems (ERS) for the Netherlands

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ERS can be a cost-effective way of achieving Zero Emission Road Transport

This study shows how an ERS network on the main motorways in the Netherlands can be profitable under certain conditions. It also shows how ERS can be a cost-effective way of reducing carbon emissions. 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 battery electric vehicles (BEVs), and also instead of diesel or hydrogen trucks. This is true for road transport with medium daily distances (from 180 to 300 km), but even more so for long-haul transport (over 300 km per day). The availability of an international network is obviously important for a large part of this transport. The study has also clearly shown 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 ERS trucks (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 in BEV charging costs, and, partly as a result, lower-than-expected use of the ERS system. In view of the many uncertainties that remain, we would emphasise that these conclusions depend on a number of developments, which must therefore be closely monitored, and that additional research is needed on a number of points.

Abstract

Follow-up to technical study

The Dutch Ministry of Infrastructure and Water Management (I&W) is promoting the transition to sustainable, zero-emission (ZE) road transport. As part of this initiative, a study was initiated to ascertain the potential of Electric Road Systems (ERS) for heavy goods vehicles (HGVs).

Using ERS technology, vehicles are supplied with electricity while on the road. The most obvious system for this (based on current knowledge) is an overhead line above the right-hand lane of motorways, where electric HGVs are supplied with electricity via a pantograph (similar to a trolleybus). In this report, we assume this technology will be used. As a result, the HGVs could be operated with much smaller batteries than fully battery electric trucks. Outside the ERS network, the HGVs could continue to run on battery (or possibly hydrogen or fossil fuels).

On the basis of a previous study, conducted by Movares[1], ERS appears to be a potentially attractive technology for making Dutch road transport more sustainable. This was what prompted the Dutch Ministry of Infrastructure and Water Management to commission this in-depth study into the cost-effectiveness of ERS in achieving its policy objectives. The study was based on existing data and information, building on the research of Movares.

Three ERS network alternatives studied

The main added value is that in this study we have considered ERS from the business perspective (cost effectiveness) of transport operators and freight forwarders. Considering a number of network alternatives,

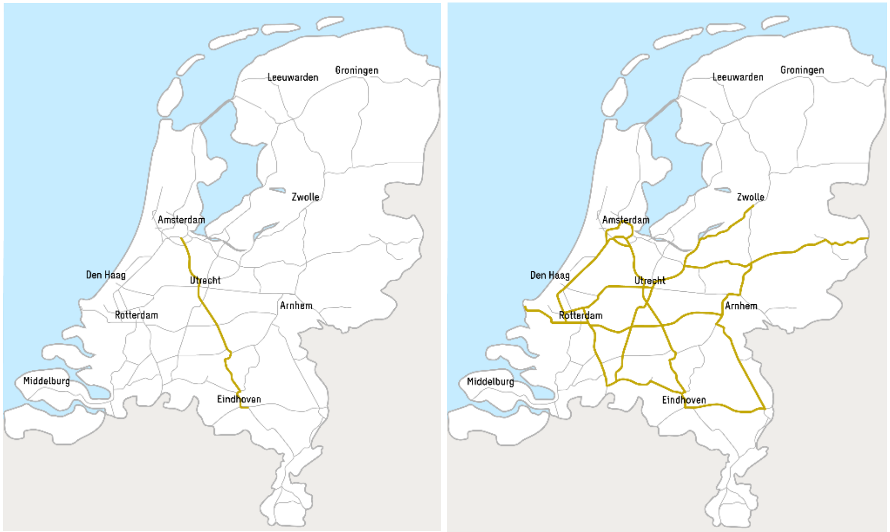
[1] Movares (2020), *Verkenning Electric Road Systems*

we looked at how the Total Cost of Ownership (TCO[2]) of HGVs using ERS (Overhead catenary Battery Electric Vehicles, O-BEVs for short) compares with fully battery operated electric HGVs (Battery Electric Vehicles, BEVs). Based on the above, we estimated the use of ERS and the external effects such as the impact on climate targets.

The study focused on the following three ERS network alternatives:

- Alternative 1: ERS on the A2 motorway between Amsterdam and Eindhoven (125 kilometres x 2 directions). This is a stretch of motorway with relatively heavy freight traffic.
- Alternative 2: A "core network" with ERS on the A roads where HGV intensities are highest (980 kilometres x 2 directions).
- Alternative 3: in which the entire A-road network is equipped with ERS (about 2,500 kilometres x 2 directions).

Figure S.1: ERS network alternatives 1 (left) and 2 (right)



[2] These are the total costs over the entire lifetime of the HGV, i.e. capital expenditures as well as maintenance and energy costs.

Figure S.2 ERS network alternative 3

The TCO of HGVs using ERS was determined for these network alternatives. They were compared with fully battery electric HGVs because in the future these will be more attractive than, for example, diesel and hydrogen HGVs. Logically, the TCO of the O-BEV becomes more attractive when more HGVs use the system. This reduces the system costs per vehicle-kilometre. In addition, HGVs with long daily distances derive greater benefit from an O-BEV than HGVs with shorter daily distances[3]. We therefore based our calculations on different daily distances.

Larger ERS networks could be cost-effective in the Netherlands

The conclusion is that alternative 1 leads to a higher O-BEV TCO than the BEV alternatives in all cases. In the basic analyses of alternatives 2 and 3, the O-BEV TCO is less than the BEV TCO. For a transport operator, an O-BEV is therefore cheaper than a BEV.

It takes a number of years to build an ERS network (estimated at three to seven years for the alternatives considered). Moreover, it will take several years before the system is fully utilised. Infrastructure and electricity costs will be relatively high during this "assimilation period". If these costs are included, the TCO for O-BEVs (for alternatives 2 and 3) remains competitive when HGVs with daily distances of 150 kilometres and above use the system.

[3] After all, the greater the daily distance, the heavier (and therefore more expensive) the battery needed for a BEV. This does not apply to O-BEVs.

It is important to realise that these calculations assume that the ERS infrastructure will have to pay for itself by means of a mark-up on the electricity purchased by the users. Recycling the revenue from the HGV toll may also offer opportunities for funding all or part of the infrastructure or making ERS more financially attractive in some other way. This could make ERS attractive for larger numbers of HGVs if necessary.

Cost-effectiveness does not necessarily mean that ERS will be an instant success, because a transport operator naturally looks at more than just TCO when choosing a drive technology. Examples of these factors include the reliability of the system, the size of the network and a competitive supply of trucks. Other important parties who are therefore vital to the success of ERS are the freight forwarders (by asking for sustainable transport and providing security through long-term contracts), truck manufacturers/OEMs (ensuring an adequate supply) and leasing companies (attractive lease structures).

ERS is a cost-effective way of reducing carbon emissions
Looking at its social impact, another major conclusion is that an ERS network can help reduce carbon emissions produced by road transport, especially if it is an international network that is being built relatively quickly. It is estimated that in alternative 3 about one third of the carbon emissions from all road freight transport (excluding delivery vans) can be prevented by 2030, assuming the system is fully operational by then. It is just under 20 percent for alternative 2, and 0.2 percent for alternative 1.
The assumption is that O-BEVs will replace diesel HGVs (or combinations) used for longer journeys. According to recent studies by TNO and EV Consult, the battery electric vehicles expected to arrive on the market by 2040 are mainly lighter vans driving relatively short distances. ERS is particularly attractive for HGVs travelling longer distances. So, for the time being, the two technologies are complementing, rather than cannibalising, each other. It is important to note, however, that car manufacturers may bring attractive BEV trucks to the market sooner than currently expected. For example, Tesla has announced it will be launching a price-competitive truck this year which can transport over 36 tonnes over 700 kilometres without recharging[4]. If Tesla (or another manufacturer) can deliver this and also deliver it in large numbers, this could herald a significant acceleration of the projections made for BEV and some or all of the foundations supporting ERS could crumble. It is therefore important to monitor the situation closely.

Other social impacts
Other potentially important social impacts are:

- the impact on road safety. The system must, of course, be safe. There are still questions about this, but it seems technically feasible to guarantee safety.
- labour shortages (displacement). The skilled workers needed to construct ERS are in short supply and are also needed for other projects in the energy transition. The same applies to the installation of charging points for BEVs. It is therefore necessary to weigh up the options.
- the capital expenditures required on the deeper electricity network (the medium and high voltage network), and how they compare to a scenario with more rapid chargers for BEVs.
- the impact of copper abrasion on the environment and health and other environmental impacts.
- and the impact on the landscape.

[4] See, for example, https://www.tesla.com/nl_NL/semi

The nuisance caused by the construction work on ERS appears to be limited. This is not a decisive factor if the work can be carried out at night with only one lane closed, especially if it can be combined with regular maintenance of the right-hand lane. Other impacts that seem to be of minor importance for deciding between ERS and battery-electric vehicles are the scarcity of the mineral resources[5] needed for batteries and ERS and the production of other emissions.

Results sensitive to significantly different assumptions
Prompted by the major uncertainties involved, a number of sensitivity analyses were also carried out. These show that the TCO of the O-BEVs, especially those aimed at the medium distance (180-300 kilometres per day) [6], are sensitive to other assumptions. The main sensitivity was found in the cost of charging BEVs, which are significantly lower at the depot (on company premises, usually at night) than on the road. If BEVs could charge entirely at the depot, the TCO of BEVs would almost always be more favourable than the TCO of an O-BEV. In addition, the demand for ERS from the logistics sector is obviously an important factor. With transport demand halved, there would be insufficient volume to make ERS profitable. ERS would then no longer be a cost-effective alternative to a BEV. A thirty percent drop in expected demand, a 2.5 percent higher discount rate and a doubling of the capital expenditures on ERS would make a BEV more attractive, especially for HGVs with daily distances of up to 150 kilometres.

Summary of sensitivity analyses carried out

Sensitivity analysis	Effect
ERS usage 50% lower than estimated	TCO of O-BEV becomes less favourable than TCO of BEV
On-road charging is no longer necessary for BEVs	TCO of O-BEV becomes less favourable than TCO of BEV
ERS usage 30% lower than estimated	TCO of O-BEV only more favourable if trucks with daily distances above 120 kilometres use ERS
Construction period three years longer	TCO of O-BEV only more favourable if trucks with daily distances above 120 kilometres use ERS
Discount rate 4.1%	TCO of O-BEV only more favourable if trucks with daily distances above 120 kilometres use ERS
50% increase in capital expenditures	TCO of O-BEV only more favourable if trucks with daily distances above 120 kilometres use ERS
Less fixed annual patterns for HGVs	TCO of O-BEV only more favourable if trucks with daily distances above 120 kilometres use ERS

[5] This does not mean that these mineral resources will not become scarce. Access to these mineral resources is also becoming increasingly geopolitical, which could lead to price fluctuations.
[6] And therefore compete with a relatively cheap BEV because the battery pack can be limited.

Battery costs 50% lower	TCO of O-BEV only more favourable if trucks with daily distances above 150 kilometres use ERS

Monitoring uncertainties and further research

The main conclusion from this study is that an ERS network in the Netherlands, under certain conditions, could be a cost-effective way of achieving significant reductions in carbon emissionsfrom road transport. In view of the many uncertainties that remain, we would emphasise that these conclusions depend on a number of developments, which must therefore be closely monitored, and that additional research is needed on a number of points.

The following developments are important for ERS and should be closely monitored:

- A specifically important point to be monitored is the development and launch of new low cost, long-range battery-electric trucks, such as the Tesla Semi.
- Trends in battery prices, the number of charging cycles, vehicle range and other qualities could have a significant impact on the TCO of BEVs and therefore also on how it compares with the TCO of O-BEVs.
- Static on-road charging and depot charging incurs considerable costs. If static on-road charging becomes cheaper, or less necessary, the TCO of BEVs will drop.
- OEMs[7]: For an ERS network to be successful, an adequate and competitively priced range of O-BEVs must be available. At the moment, this is not the case, and the number of manufacturers who are seriously working on this is still limited. Of course, this range should keep pace with the development of the ERS network.
- The development of ERS technologies other than overhead lines. Germany, for example, has initiated an ERS pilot involving inductive charging.
- Developments centring on hydrogen. At present, hydrogen is not yet a competitive option for road transport as a result of higher costs and lower energy efficiency, but developments may be rapid.
- How neighbouring countries view ERS. Consultation and joint action in this regard will obviously be needed.
- This could include a joint examination of some technical elements that are the same for each country:
    - the risk and consequences of a cable break and ways of minimising the impact
    - abrasion of copper on the overhead line and its impact on the environment
    - controlling the use of ERS. If too many O-BEVs are using the ERS infrastructure at the same time (close to each other), there may not be enough power.

Aspects that require further research specifically for the Netherlands are:

- Current and future logistic patterns of HGVs in the Netherlands, in particular how fixed the patterns are that HGVs travel during the year. The assumptions made in this study were based on expert judgement.
- The investment required in the electricity network. This includes both the specific investment needed to create an extensive ERS network and the investment required in the high- and medium-voltage network in the Netherlands to provide the ERS network with sufficient peak capacity everywhere. This

[7] Original Equipment Manufacturers. This refers to the truck manufacturers, including component suppliers.

should be compared to the same investment that would be needed without ERS, when BEVs would have to be charged at charging points and rapid chargers.

- Labour shortages and the energy transition. More in-depth research is needed to ascertain the occupations which are relevant to ERS and electric charging (and to what extent), the expected shortfall in these occupations and the projects in which this scarce capacity can best be used. This research should take a wide-ranging look at various possible developments/investments required to achieve the energy transition for which scarce labour resources are needed.

Answers to the research questions

The Ministry's research questions are answered one by one below. We would like to point out that we have had to make a number of major assumptions in this study because some aspects are still unknown and because important future developments are still uncertain.

Vehicle fleet.

Question:
What is the minimum transition from the (freight) vehicle fleet (RDW Category N3) to ERS solutions:
- to be sufficiently attractive to make freight forwarders and transport operators switch to them
- to make a substantial contribution to reducing carbon emissions from heavy goods traffic.

The analysis clearly showed that ERS is dependent on achieving a critical mass of HGVs using the system. The creation of ERS along a single corridor is not attractive enough to make transport operators switch to O-BEVs. A network of the main or all motorways could be. In addition to the TCO and having a sufficiently large network, there are a number of other important conditions for attracting a critical mass of transport operators. This includes having an adequate supply of suitable trucks, the reliability and safety of the system and the reliability of competing tariffs.

Although it is difficult to estimate in this study due to the many uncertainties and dependencies, we expect that a third to half of the freight traffic would have to use ERS to make an O-BEV more attractive than a BEV in terms of cost.

Research by TNO[8] and EV Consult[9] shows the expected trends in BEV trucks in a scenario based on established policy and a scenario that also includes proposed policy.

TNO (and EV Consult's forecasts are similar) predicts that, for the various types of trucks, BEVs will become affordable and suitable as replacements for diesel trucks for part of the fleet sometime within the next eight years[10]:

[8] TNO, 2021, Aanzet tot een analysekader betreffende de ingroei en opschaling van elektrische bestel en vrachtvoertuigen in de Nederlandse vloot tot 2040

[9] EV Consult, 2020, Transitiestudie verduurzaming wegtransport

[10] In the "voorgenomen beleid" [proposed policy] column, recycling the revenue from the HGV toll is also assumed.

	Tipping point for BEV/diesel for first part of fleet	Based on established policy, share will grow		Based on proposed policy, share will grow by 2030 to
		By 2030 to	By 2040 to	
Light-duty trucks	2026	30%	70%	65%
Medium-duty trucks	2029	5%	35%	30%
Heavy-duty trucks	2026	20%	45%	40%
Tractor-trailer combinations	2027	5%	15%	10%

The study and the above overview make it clear that BEVs are expected to have market shares of 30 to 70 percent as early as 2030 and 2040, especially in the light-duty segment and for vehicles that travel relatively short distances. The light-duty trucks are the segment that travels relatively short daily distances. This study found that ERS is particularly attractive for trucks with longer daily distances, at least from 250 kilometres onwards. This is precisely the segment where TNO does not predict any major growth until 2040. Provided it is built quickly and preferably as part of an international network, an ERS network is therefore predicted (see also conditions for transport operators) to lead to earlier and greater carbon emission savings.

An important note on the studies of TNO and EV Consult is the announcement by Tesla that they are going to market a price-competitive truck (base price €150,000[11]) that can transport over 36 tonnes over 700 kilometres without recharging. If Tesla (or another manufacturer) can make this happen and also deliver them in large numbers, this could herald a significant acceleration of the projections made and actually make an ERS system redundant.

Question: When will ERS become attractive for different categories of freight forwarders/transport operators (e.g. international carriers, construction traffic, retail carriers, bus operators, etc.)?

ERS can be especially attractive for freight forwarders/transport operators who have relatively fixed patterns (i.e. travel the same routes all year round), do not travel too short daily distances and do not have their destination too far from the motorway. ERS could be attractive for (parts of) all the major subsectors, such as food, agro/food, construction and distribution transport, because they involve many fixed patterns. As the ERS network becomes larger and more deeply embedded in an international network, the fixed patterns will become a less decisive factor and ERS could also become an attractive option for very long-haul traffic[12]. The study shows that it is particularly important to have a high demand for ERS to ensure cost-effectiveness. It is therefore essential not to target just one sector, but as many as possible.

[11] In comparison, the BEV 400 in the TCO model has a purchase price of around €220,000 and a range of 400 kilometres, while the BEV 800 has a purchase price of €340,000 and a range of 800 kilometres.
[12] In this study, based on expert judgement, we assume that in alternative 1 25 percent of the trucks travel in sufficiently regular patterns for them to be replaced by an O-BEV. This rises to 65 percent in alternative 2 and to as many as 80 percent in alternative 3.

Road network

Question: How does the coverage of sections of the main road network relate to the number of transport operators who choose to make the switch to ERS? In other words, what is the minimum proportion of the main road network that needs to be equipped with overhead lines to make ERS an attractive option for transport operators? And how many additional operators will use ERS over and above this minimum coverage?

This study has made it clear that building ERS along a single corridor would not deliver an acceptable TCO because ERS would then be attractive to too few operators. The analysis shows a network covering the Randstad conurbation and the main roads in North Brabant, Gelderland, southern Overijssel and North Limburg to be the most attractive option (in terms of profitability). However, a network in which the entire motorway network is equipped with ERS also achieves a high score.

The factors affecting the use of ERS are described in the report. Besides the TCO and the characteristics of the transport used, a number of important factors are at play here, including reliability, market organisation, safety, the supply of trucks, etc.

As a result, it is currently not possible to determine exactly what the minimum network for ERS is and how many additional transport operators an expansion of the system would bring with it. The three network alternatives studied do give an indication of this.

Question: Which routes should be equipped with ERS in any case, based on the user profile that was created? If possible, this will be based on an understanding of who travels on which routes and why.

The study has shown that a network covering the Randstad conurbation and the main roads in North Brabant, Gelderland, southern Overijssel and North Limburg, naturally (or possibly) connected to the ERS network in Germany and Belgium, would already be cost-effective. And the same applies to an ERS on all motorways in the Netherlands. However, an ERS on a single route is not cost-effective.

Carbon reduction

Explain how the roll-out of ERS will contribute to the climate objectives. How many users and how many kilometres of road network with ERS will it take to bring about a desired reduction in carbon emissions?

The carbon reduction achieved by a future ERS network depends to a great extent on the way road transport emissions would develop if no ERS network were built. This does, of course, involve considerable uncertainties. Research by TNO and EV Consult shows that the largest growth of battery electric vehicles is expected on shorter distances by 2030 and also by 2040. Because ERS is particularly attractive for long-haul transport, we expect the two systems to be complementary for the time being. Taking into account the expected emissions from HGVs by 2030 and the fact that the electricity mix in the Netherlands will not be fossil-free by 2030, the reduction in carbon emissions from road freight transport in the Netherlands in alternative 3 may amount to about one third (assuming full utilisation of ERS and the electricity mix in 2030). This would be 16 to 18 percent in alternative 2, and 0.2 percent in alternative 1. As far as the development of carbon savings is concerned, this will increase after 2030 because the electricity mix will become less and less fossil-based. On the other hand, increasingly attractive BEV trucks are expected to enter the market for longer distances, especially after 2040. An increasing proportion of carbon savings would therefore have been achieved even without ERS.

Carbon savings by 2030 in the two WLO scenarios (assuming ERS is fully operational and in use by then)

	High		Low	
	Carbon saved (tonnes*1000)	As a percentage of road freight transport emissions	Carbon saved (tonnes*1000)	As a percentage of road freight transport emissions
Alternative 1	11	0.2%	9	0.2%
Alternative 2	937	18%	820	16%
Alternative 3	1734	33%	1544	31%

Cost-effectiveness

Question: How does the cost per tonne of carbon saved compare with the cost per tonne of carbon saved by any other measures the state can deploy to reduce the carbon emissions of category N3 trucks?

ERS can lead to a reduction in carbon emissions without costing the state money because ERS can be a sound business case. And the transport operators are not more expensive either. So it is a very cost-effective way of saving carbon.

The analysis shows that an extended ERS network (alternative 2 or 3) can deliver a TCO that could compete with battery electric driving, even taking the start-up losses into account. These start-up losses are expected to be recovered over the lifetime of the network. BEVs (and therefore also O-BEVs) are expected to be competitive with diesel trucks within a few years (either through market trends or levies on diesel or carbon emissions), which means that the investment required from the state will be very limited. At most, bridging finance will be needed for the period from the start of construction until the network is fully operational.

Terms and abbreviations used

BEV	Battery Electric Vehicle; fully battery-operated vehicle
BEV-400	A battery electric vehicle with a range of 400 km
BEV-800	A battery electric vehicle with a range of 800 km
CAPEX	Capital Expenditures
ERS	Electric Road Systems; roads on which vehicles can charge while on the road
FCEV	A fuel cell electric vehicle with a range of 800 km
L2	Category of heavy goods vehicle up to 12.8 metres in length (mostly rigid trucks)
L3	Category of heavy goods vehicle over 12.8 metres in length (mostly tractor-trailer combinations)
LCA	Life Cycle Analysis; method for determining the total environmental impact of a product throughout its life cycle
LMS	National model system (Dutch: *Landelijk model systeem*); strategic traffic and transport model used in infrastructure decision-making. This has been used to make forecasts for 2030 and 2040 for the high and low scenarios.
MKEA	Social Cost Effectiveness Analysis (Dutch: *Maatschappelijke Kosteneffectiviteitsanalyse*)
N2	Category of HGV exceeding 3.5 tonnes in weight but not exceeding 12 tonnes
N3	Category of HGV exceeding 12 tonnes in weight
O-BEV	Overhead catenary Battery Electric Vehicle
O-BEV 100	Battery electric vehicle suitable for dynamic charging via a pantograph on the overhead line, plus a 100 km range when on battery electric power
O-BEV 250	Battery electric vehicle suitable for dynamic charging via a pantograph on the overhead line, plus a 250 km range when on battery electric power
OEM	Original Equipment Manufacturer
O-HEV	Diesel-hybrid electric vehicle suitable for dynamic charging via a pantograph on the overhead line, plus a 2 km range when on battery electric power. Outside the ERS system, it runs on diesel.
OPEX	Operating Expenses
TCO	Total Cost of Ownership; the total cost over the lifetime of the vehicle, i.e. both capital expenditures and maintenance and energy costs
TTW	Tank To Wheel; part of the energy chain from fuel tank to wheels
WLO High	*Toekomstverkenning Welvaart en Leefomgeving* (High Future Scenario); scenario drawn up by the Netherlands Environmental Assessment Agency and the Netherlands Bureau for Economic Policy Analysis. The High Scenario combines relatively high population growth with high economic growth. The WLO scenarios were modelled using the LMS.
WLO Low	*Toekomstverkenning Welvaart en Leefomgeving* (Low Future Scenario); scenario drawn up by the Netherlands Environmental Assessment Agency and the Netherlands Bureau for Economic Policy Analysis. The Low Scenario combines limited demographic growth with moderate economic growth.

- WTW — Well To Wheel; part of the energy chain from fuel extraction to wheels
- WTT — Well To Tank; part of the energy chain from fuel extraction to tank
- ZE transport — Zero-emission transport; forms of transport with no carbon emissions

1. Introduction

1.1 Rationale and question studied

The Dutch Ministry of Infrastructure and Water Management (I&W) is promoting the transition to sustainable, zero-emission (ZE) road transport. As part of this initiative, a study was initiated to ascertain the potential of (ERS) Electric Road Systems for heavy goods vehicles (HGVs).

In these Electric Road Systems (ERS), vehicles are supplied with electricity while on the road. The most obvious system for this (which is also assumed in this report) is an overhead line above the right-hand lane of motorways, where electric HGVs are supplied with electricity via a pantograph (similar to a trolleybus). As a result, the HGVs can make do with smaller batteries with less capacity. When they leave the ERS network, the HGVs can continue their journey with energy stored in the vehicle: in a battery, in hydrogen or in renewable or fossil fuels.

On the basis of a previous study conducted by Movares[13], ERS appears to be a potentially attractive technology that would help make Dutch road transport more sustainable. This was what prompted the Dutch Ministry of Infrastructure and Water Management to commission this in-depth study into the cost-effectiveness of ERS in achieving its policy objectives.

Question

The key questions in this study are[14]:

Vehicle fleet.

1. What is the minimum transition from the (freight) vehicle fleet (RDW Category N3) to ERS solutions:
    - to be sufficiently attractive to make freight forwarders and transport operators switch to them
    - to make a substantial contribution to reducing carbon emissions from heavy goods traffic.
2. When will ERS become attractive for different categories of freight forwarders/transport operators (e.g. international carriers, construction traffic, retail carriers, bus operators, etc.)?

Road network

3. How does the coverage of sections of the main road network relate to the number of transport operators who choose to make the switch to ERS? In other words, what is the minimum proportion of the main road network that needs to be equipped with overhead lines to make ERS an attractive option for transport operators? And how many additional operators will use ERS as a result of what level of additions to this minimum coverage?
4. Which routes should be equipped with ERS in any case, based on the user profile that was created? If possible, this will be based on an understanding of who travels on which routes and why.

Carbon reduction

13 Movares (2020). Verkenning Electric Road Systems

14 Literal formulation from the project description

5. Explain how the roll-out of ERS will contribute to the climate objectives. How many kilometres of road network with ERS will equate to how many users and what level of carbon reduction will be achieved as a result?

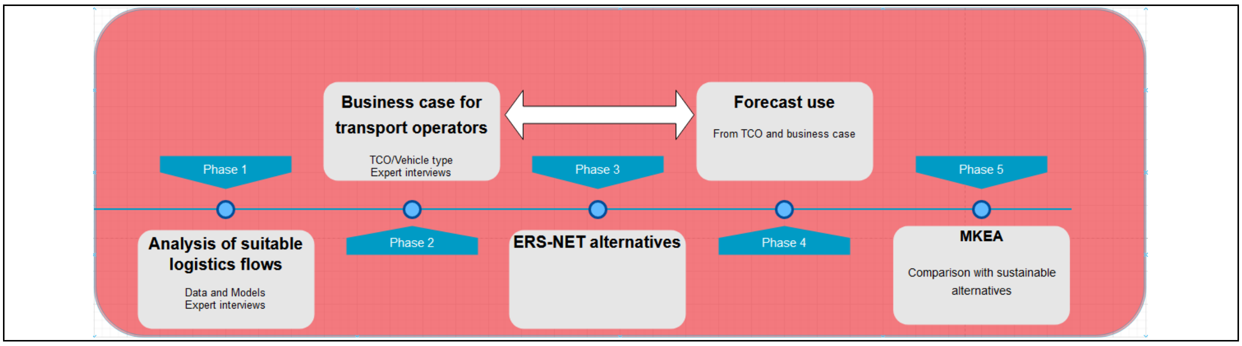
Cost-effectiveness

6. How does the cost per tonne of carbon saved compare with the cost per tonne of carbon saved by any other measures the state can deploy to reduce the carbon emissions of category N3 trucks?
7. What other benefits and costs for users and society (besides the reduction in carbon emissions) can be identified and quantified as a result of the minimum level of investment in ERS? Costs could be: horizon pollution, road safety and particulate emissions due to abrasion of the overhead line. Benefits could include: less peak load on the energy grid, more logistical flexibility through dynamic charging, savings on mineral resources due to the smaller battery required.

1.2 Approach to the study

This study consisted of five phases. The interests of the transport operators and a good understanding of road transport flows were the starting point for the ERS network alternatives and the final social impact analysis. After all, implementation of the ERS network can only be successful on routes with sufficient HGV movements and if transport operators find it economically attractive, at least compared to other options for sustainable transport.

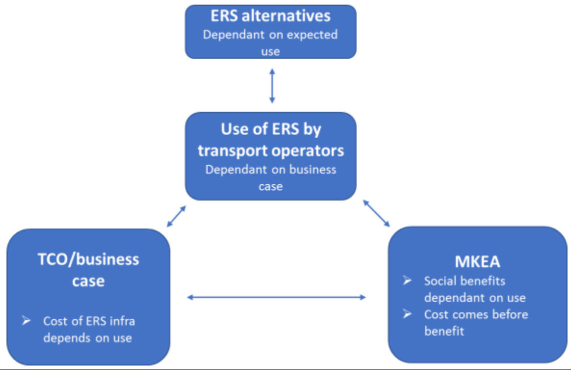
Figure 1.1. Outline of approach



The first two phases of the study therefore focused on analysing suitable logistics flows and the TCO (Total Cost of Ownership) and business case of the transport operators.
After setting out the ERS-network alternatives (phase 3), we used LMS modelling (national model system) to look again at the transport operators and traffic flows for which the ERS alternatives are attractive and computed the expected demand and the resulting cost of using ERS. By comparing the resulting TCO with the TCO of battery electric alternatives, it was ascertained whether ERS is competitive and the investment in ERS is cost-effective[15].

[15] We paint a picture of the social cost-effectiveness, but it is not a real social cost-effectiveness analysis (MKEA), because there is too much uncertainty surrounding the "base case" or the situation as it would develop without ERS.

Figure 1.2. Explaining the chicken-and-egg problem



So there is a necessary iteration in the study: the cost of using ERS determines the TCO and attractiveness for road transport operators. At the same time, this cost depends on the use of the ERS: the more vehicles that use it, the cheaper it is to use.

The study is based on desk research, expert interviews, data analysis and LMS modelling. A model was built on that basis. The study was supervised by a supervisory group from the Dutch Ministry of Infrastructure and Water Management.

1.3 Reader's guide

This chicken-and-egg problem is reflected in the analysis line of the report: Section 2 begins with an analysis of the logistics flows to determine the flows for which ERS could be an attractive option. In Section 3, we look at the TCO of ERS compared to other Zero Emission alternatives and consider factors other than the TCO that are relevant to transport operators. Based on Sections 2 and 3, we have defined three network alternatives, as described in Section 4, where we immediately show the resulting demand and associated TCO. In Section 5, we describe the relevant social impact. Thereafter, in Section 6, we present a number of sensitivity analyses of the most important sensitivities and uncertainties. Finally, in Section 7, we conclude with a description of the uncertainties to be monitored or investigated.

2. Analysis of road transport flows

Based on international research, ERS seems to be particularly attractive for HGVs travelling long distances in a day. And this makes sense, because the greater the battery capacity that can be saved in an HGV, the more attractive ERS becomes for transport operators. We also know that ERS has to be used a lot to make it attractive. In order to identify potentially attractive ERS networks, we must therefore have a picture of the roads where there is a lot of freight traffic, especially long-haul freight traffic. The pattern that the HGVs follow throughout the year is also relevant. ERS can be particularly attractive for HGVs that follow fixed patterns. Of course, this also depends on the interlinking of the network, which means that an ERS network becomes more attractive the larger it is, as international research shows[16]. After all, as the network expands, a larger proportion of HGVs will be able to cope with power from ERS and a small battery.

2.1 Road transport in the Netherlands, a lot of domestic transport, major differences in daily distances

The total performance in vehicle-kilometres on Dutch territory is shown in Table 2-1.

Table 2.1: Annual vehicle-kilometre performance of Dutch HGVs on Dutch territory by direction, 2019 (in kilometres x million)

Type of transport	Kilometres (x million)
Domestic transport in the Netherlands	4,314
International transport leaving the Netherlands	391
International transport entering the Netherlands	360
Transit through the Netherlands without transshipment	29
Miscellaneous	0
Total	**5,094**

Source: Statistics Netherlands

Extensive research on road freight transport was conducted by Statistics Netherlands in 2018 and 2019 (source used: Statistics Netherlands: Base data for road freight transport 2019). The source of the study is an extensive survey of road transport operators.
A further breakdown of road freight transport by type of transport and own-account versus commercial freight transport is shown in Table 2.2.

[16] See, for example:
- Florian Hacker, Patrick Plötz, Julius Jöhrens, 2020. Electric roads for the German climate protection strategy for freight transport? A review and synthesis of market diffusion and electrification studies
- Hasselgren, Björn, Näsström, Elin (Swedish Transport Administration, 2021) Electrification of Heavy Road Transport: business models phase 5
- D.T. Ainalis, C. Thorne, and D. Cebon (centre of sustainable road freight) 2020. White Paper: Decarbonising the UK's Long-Haul Road Freight at Minimum Economic Cost

Table 2.2: Number of journeys by type of transport, carrier and vehicle (x1,000), 2019

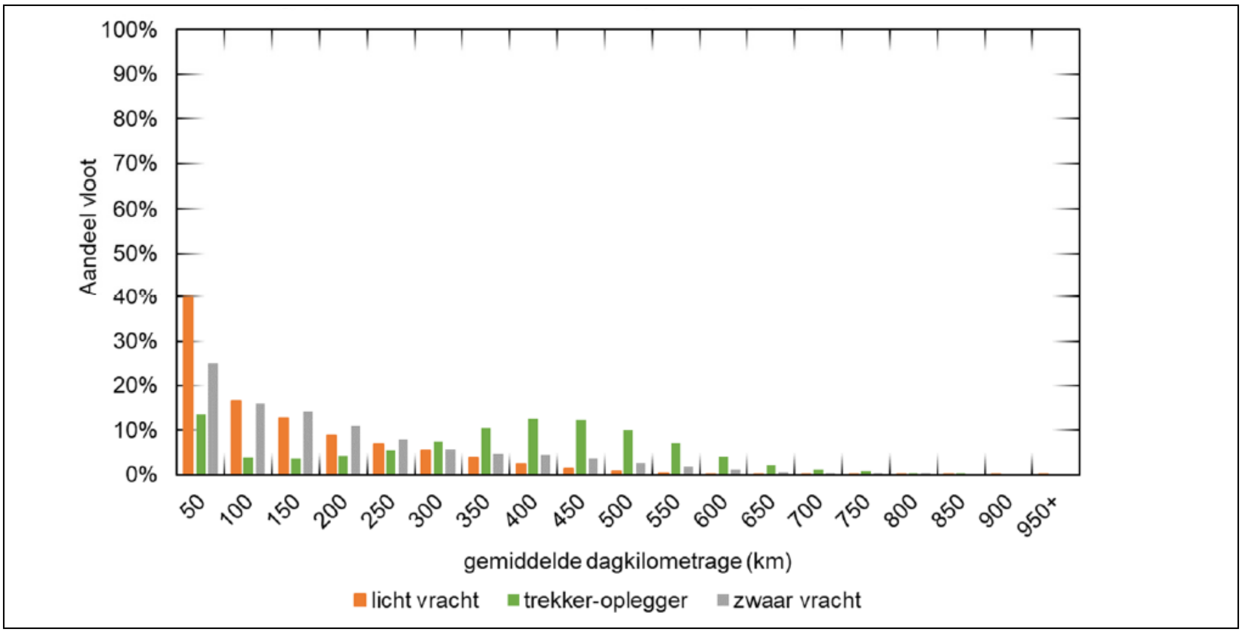
	Commercial transport	Own-account transport (by freight forwarder)	International HGVs	Total
Domestic transport in the Netherlands	52,110	19,798	1,491	**73,399**
International transport leaving the Netherlands	3,995	735	3,696	**8,426**
International transport entering the Netherlands	3,853	676	3,774	**8,303**
Transit through the Netherlands without transshipment	370	51	1,142	**1,563**
Miscellaneous	2,433	181		**2,614**
Total	**62,762**	**21,420**	**10,103**	**94,285**

Source: Statistics Netherlands

Daily distances

Looking at the daily distances, there are big differences between the different types of HGVs. Research by TNO shows this[17]. A Dutch HGV drives 55,000 kilometres a year on average, but for rigid trucks this is only 34,000, while tractor-trailers travel an average of 70,000 kilometres a year. This can also be seen in Figure 2.1. For light goods vehicles (and also for heavy goods vehicles), daily distances of up to 250 kilometres are the most common; 70 percent of these vehicles drive an average of 110 kilometres or less per day. Most tractor-trailers drive between 300 and 600 kilometres. Forty percent drive an average of 350 to 500 kilometres a day.

Figure 2.1. Vehicle fleet by daily distances



Source: Statistics Netherlands (2021)

[17] TNO, 2021, Aanzet tot een analysekader betreffende de ingroei en opschaling van elektrische bestel en vrachtvoertuigen in de Nederlandse vloot tot 2040. The definitions of light and heavy-duty vehicles are not entirely clear from the report.

The conclusion is that Dutch HGVs have by far the largest share of domestic transport, both in terms of the number of journeys and kilometres travelled. Furthermore, there is a big difference between the average daily distances, with tractor-trailers having much higher average daily distances than rigid trucks.

Continued future growth

The forecasts for the development of freight transport over the next 20-30 years, as included in the WLO[18] scenarios, show that road transport will increase relatively strongly[19]. It is predicted that relatively more long and heavy vehicles will be used and that the load factor will increase due to efficiency improvements. This will result in fewer, especially empty, journeys. On the other hand, distribution networks are becoming more sophisticated, which means that more transport will routed via distribution centres. This will increase the number of journeys and could also lead to longer average journeys. On balance, the number of journeys is increasing, especially for longer and heavier vehicles. The increase in road transport also feeds into international transport, which can increase the length of journeys. The PBL expects that the spread of spatial development within the activity pattern in the Netherlands may also lead to more and longer trips.

2.2 Distribution networks are located in and around the Randstad conurbation

The use of the road network by freight traffic is determined by the transport and distribution structure of the main economic sectors in the Netherlands.

Food sector

The major building blocks of the food sector's distribution system in the Netherlands are the supply of products from the large producers, distribution from the agricultural sector (including export) and distribution to the retail sector. A characteristic feature of the large producers is that they have often traditionally stayed close to the place where they were established. One example is HAK, whose logistics centre is located in Giessen in North Brabant. This structure ensures good distribution across the country. North Brabant and the eastern part of the Netherlands are home to a relatively large number of producer headquarters.

Horticultural distribution is partly concentrated in six Greenports, four of which are located in the Randstad conurbation (Figure 2.5).

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[18] Toekomstverkenning Welvaart en Leefomgeving; In this publication, the Netherlands Environmental Assessment Agency and the Netherlands Bureau for Economic Policy Analysis (PBL) developed a high and low scenario.

[19] Freight transport and seaports. Scenario studies 2030 and 2050, PBL, 2016

Figure 2.5: Location of the six Greenports (source: greenportholland.com)

Distribution to retail/supermarkets is mainly effected via the supermarkets' large regional distribution centres (see Figure 2.6). The locations of these distribution centres are a major factor in determining the structure of supermarket logistics. Obviously, they are largely geared to population concentrations in line with the structure of the main road network.

Figure 2.6: Supermarket distribution centres (source: Supply Chain Magazine)

Construction sector

According to Statistics Netherlands, 20 percent of freight traffic is related to the construction sector. The traffic logically follows the distribution of building activities across the country - it is concentrated in the Randstad conurbation.

Other subsectors

The flows of online orders and other parcel services are channelled through the distribution centres belonging to the parties concerned. The top 10 of these parties account for about 50 percent of the parcels. Important locations include bol.com (headquartered in Waalwijk), Wehkamp (Zwolle) and Zalando (Bleiswijk). PostNL has 25 distribution centres in the Netherlands, and DHL 16. In general, it is safe to say that the location of distribution centres across the country follows the distribution of population concentrations, with the less densely populated areas being served from distribution centres located near the more densely populated areas. Most distribution centres are therefore located in the same area as most HGVs: Randstad, Gelderland, North Brabant, North Limburg and South Overijssel.

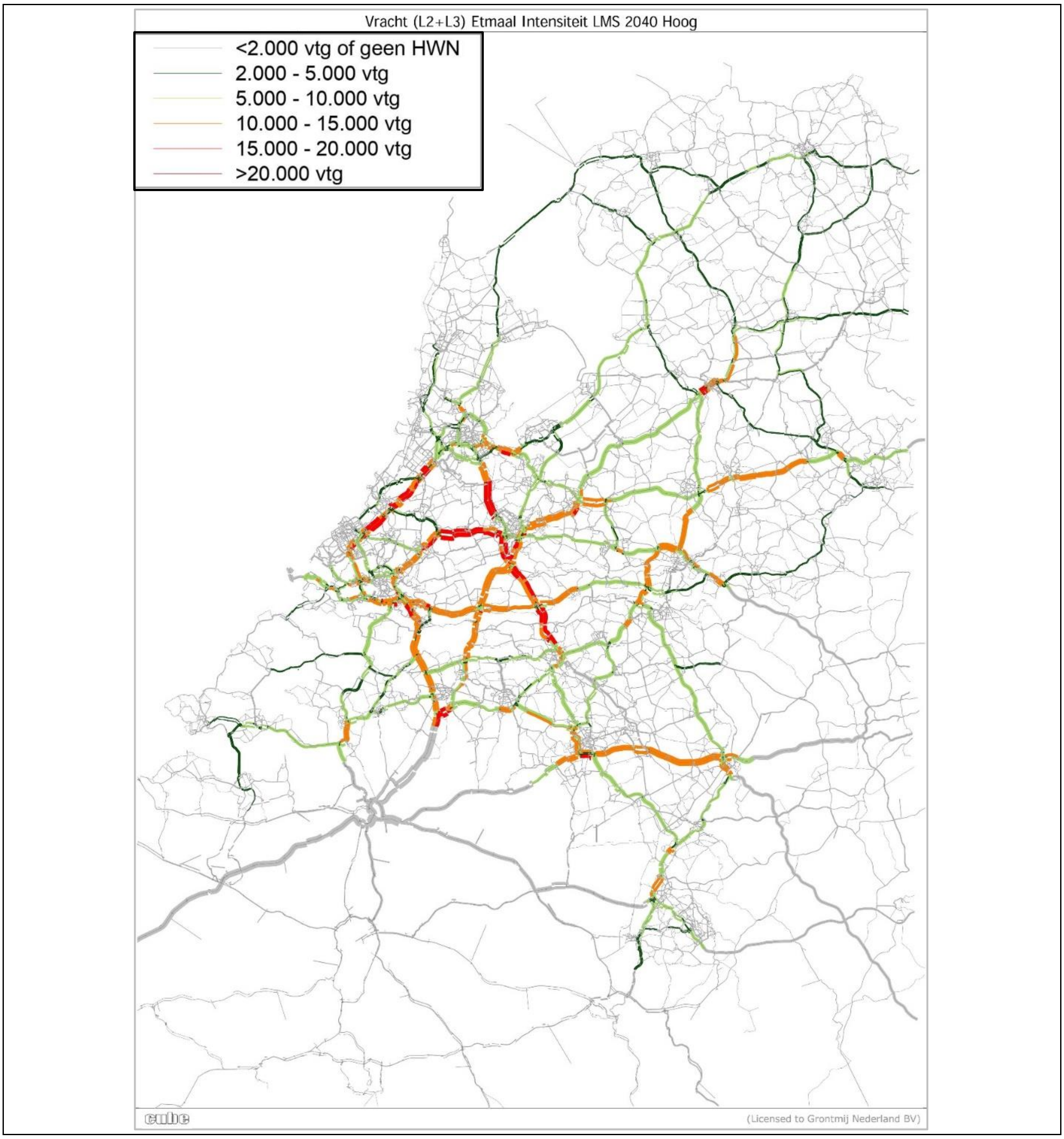
Rotterdam is the main hub for the flows that result from the fact that the Netherlands is a link in the international logistics chain, while Duisburg is the main final destination for transport to Germany. To the south, most transport goes to Antwerp.

2.3 Distribution across the network

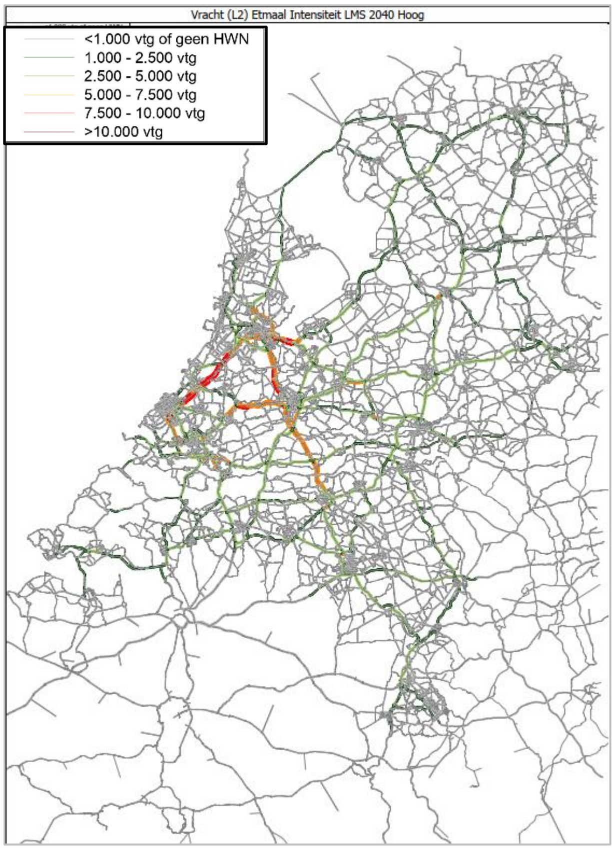
We used the national model system (LMS) to examine the HGV intensities expected by 2030 and 2040. The figures below illustrate this (for the "WLO High" development scenario). Vehicles are divided into categories L2 (trucks up to 12.8 metres in length, often rigid trucks[20]) and L3 (longer than 12.8 metres, often tractor-trailer combinations). The current distribution in terms of journeys between L2 and L3 is 37 and 63 percent respectively. The proportion of L3 trucks is expected to increase to 65 (WLO Low) and 74 percent (WLO High) respectively by 2040.

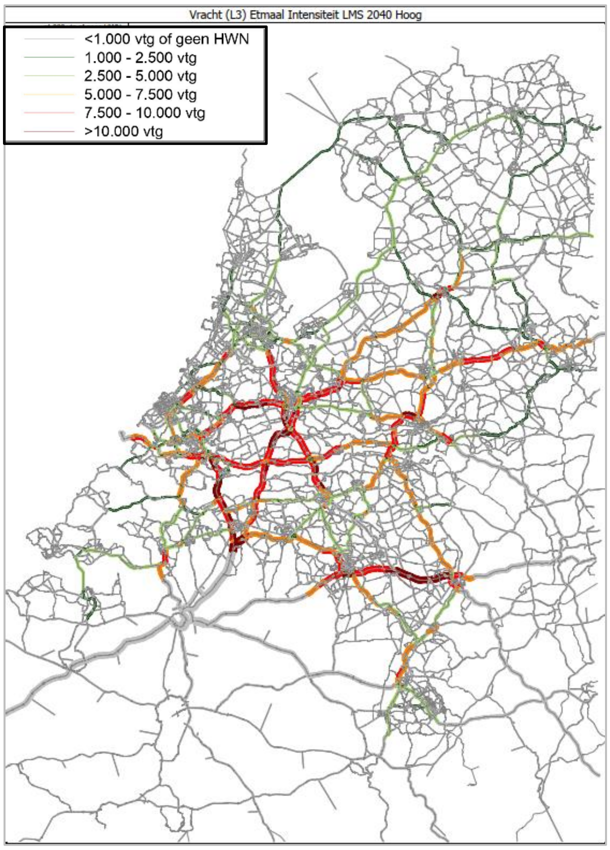
[20] Vans have been filtered out.

Figure 2.7: Daily intensities for LMS by 2040 High L2 and L3 combined



Figures 2.8 and 2.9: Daily intensities for LMS by 2040 High L2 and L3 separately[21]





It can be clearly seen that freight traffic is concentrated in the Randstad conurbation and in North Brabant, Gelderland, North Limburg and the south of Overijssel. The A2, the A4, the A12 and part of the A1 are the main routes when it comes to rigid trucks (L2).

2.4 Conclusions

We can conclude that the majority of freight flows are domestic and that the most heavily used motorways are in the Randstad conurbation, North Brabant and Gelderland (and southern Overijssel and North Limburg). The main distribution networks used by the sub-sectors also fall within this area. The possibility of having an ERS network in this part of the country therefore seems worth exploring.
In terms of daily distances, there are large differences between tractor-trailer combinations, which on average cover much longer distances, and rigid trucks, many of which cover relatively short distances.

[21] Please note that the legend differs from that in Figure 2.2.

3. Cost comparison of zero-emission freight transport

3.1 TCO of zero-emission transport is becoming competitive

In any analysis of the cost-effectiveness of ERS, it is important to ensure that for the transport operator the use of ERS is competitive with alternatives. The Total Cost of Ownership (TCO) of the transport operators is taken into account when considering their business case. The TCO consists of two elements: the capital cost (CAPEX) and the operating cost (OPEX) over the lifetime of the vehicle. For this reason, a TCO of ERS users (O-BEV & O-HEV) is compared with technological alternatives (see Table 3.1).

Table 3. Truck alternatives

Vehicle alternative	**Description**
Diesel[22]	A vehicle powered by an internal combustion engine and fuelled by diesel fuel
FCEV	A fuel cell electric vehicle with a range of 800 km
O-HEV	Diesel-hybrid electric vehicle suitable for dynamic charging via a pantograph on the overhead line, plus a 2 km range when on battery electric power. Outside the ERS system, it runs on diesel.
O-BEV 100	Battery electric vehicle suitable for dynamic charging via a pantograph on the overhead line, plus a 100 km range when on battery electric power
O-BEV 250	Battery electric vehicle suitable for dynamic charging via a pantograph on the overhead line, plus a 250 km range when on battery electric power
BEV-400	A battery electric vehicle with a range of 400 km
BEV-800	A battery electric vehicle with a range of 800 km

Movares carried out a study into this in 2020. As indicated in Movares' study, this was an initial exploration and requires further elaboration. This section describes this further elaboration of the TCO of transport operators.

The main adjustments we have made to Movares' TCO calculations are as follows:

1. Movares' study was based on the assumption that a certain number of trucks would use ERS. Our research looked into the expected demand in much greater depth, primarily based on TCO. This involved considering various network alternatives, for which the expected use of ERS has been estimated. We will return to this point in Section 4.
2. In the Movares study, conservative assumptions were used for battery performance. No residual value is assigned after the service life and the number of full charge cycles seems to be very low compared to estimates from research BY CE Delft (2020).

[22] LNG is not included in this study because it constitutes zero-emission transport. Diesel is included as the most common reference.

3. The TCO of the FCEV alternative (hydrogen) deviates significantly from the findings of the research team and the Ministry and has therefore been adjusted. This is mainly on the CAPEX side of the FCEV's TCO.
4. The study assumes one type of transport operator in terms of weight, daily distance, etc. It does not take into account the different types of transport operator, routes, weights and specific requirements.
5. The TCO assumes a fixed point in time in 2030 with a given price, it does not provide an insight into the assimilation process towards 2030. This applies to both the number of vehicles and the assimilation of charging infrastructure. The combination of these two determines the kWh price of the overhead catenary system. This is therefore a major limitation in the research carried out. We will return to this point in Section 4.

Points two and three prompted the following adjustments of the TCO calculations:

More charge cycles for batteries

Another adjustment concerns the number of full charge cycles that a battery will be able to handle over its lifetime by 2030. Movares assumed 1,250 full charge cycles, which - according to current expert estimates - is very low. Based on research by CE Delft (2020), this was increased to 5,000 full charge cycles. The effect of this is that the batteries in the tractor units no longer need to be replaced during the lifetime of the tractor unit. In the TCO calculations, this mainly affects the BEV 400.

Movares did not include the residual value of the batteries when calculating the TCO of the O-BEV and BEV alternatives. We expect there to be a market for second-hand batteries, as they can still store electricity, albeit less than when new. The residual value is based on a battery price of 25 percent of the original price for 80 percent of the original capacity. This results in a residual value of 20 percent of the original capital cost of the battery[23].

Adjustments to the FCEV alternative (fuel cell tractor unit)

The TCO of the FCEV alternative has been adjusted. In the current market, the cost of an FCEV tractor unit is over €460,000[24]. Movares' prediction that this will have dropped to €140,000 by 2030 is, in our view, too optimistic. The cost has been adjusted in line with research conducted by EVConsult for the Dutch Ministry of Infrastructure and Water Management (I&W)[25] to an amount of €264,000 by 2030.

Table 3.2: FCEV TCO comparison (indexed on the basis of 10 years and 1.61%)

Component	Movares	Adjustment
Capital cost	€140,000	€264,000
Energy costs	€422,000	€422,000
B&O	€187,000	€187,000

[23] Expert judgement based on EVConsult's market knowledge
[24] TCO-tool Topsector logistiek (2020)
[25] Transitiestudie verduurzaming wegtransport I&W (2020)

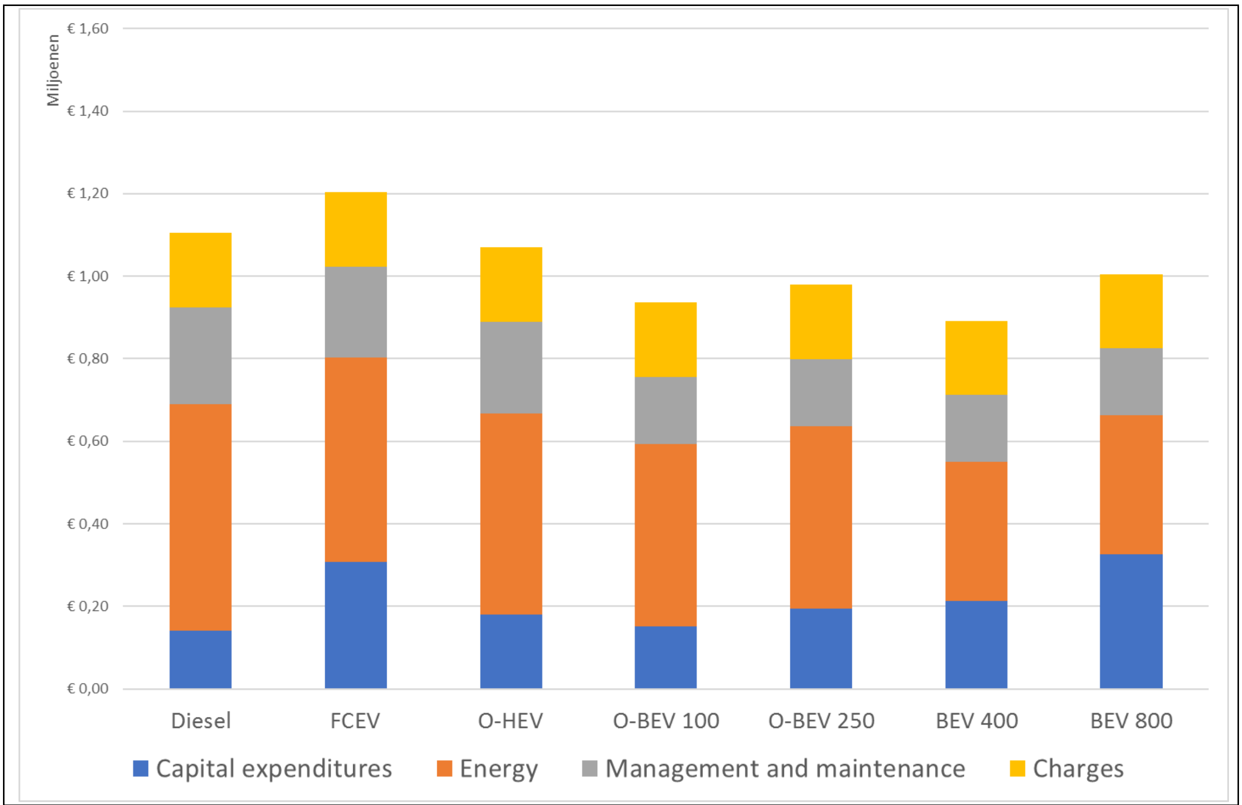
Charges	€153,000	€153,000
Total	**€1,069,000**	**€1,204,000**

The difference in capital expenditures mainly consists in the price assumptions for the fuel cell, hydrogen tank and associated electronics.

Resulting TCO

Figure 3.1 shows the TCO of the alternatives by 2030 after adjustment of the assumptions. The figure shows the total fixed and variable costs over the lifetime of the different types of HGV. The assumptions we used for the calculations can be found in Appendix 4.

Figure 3.1. TCO after adjustments



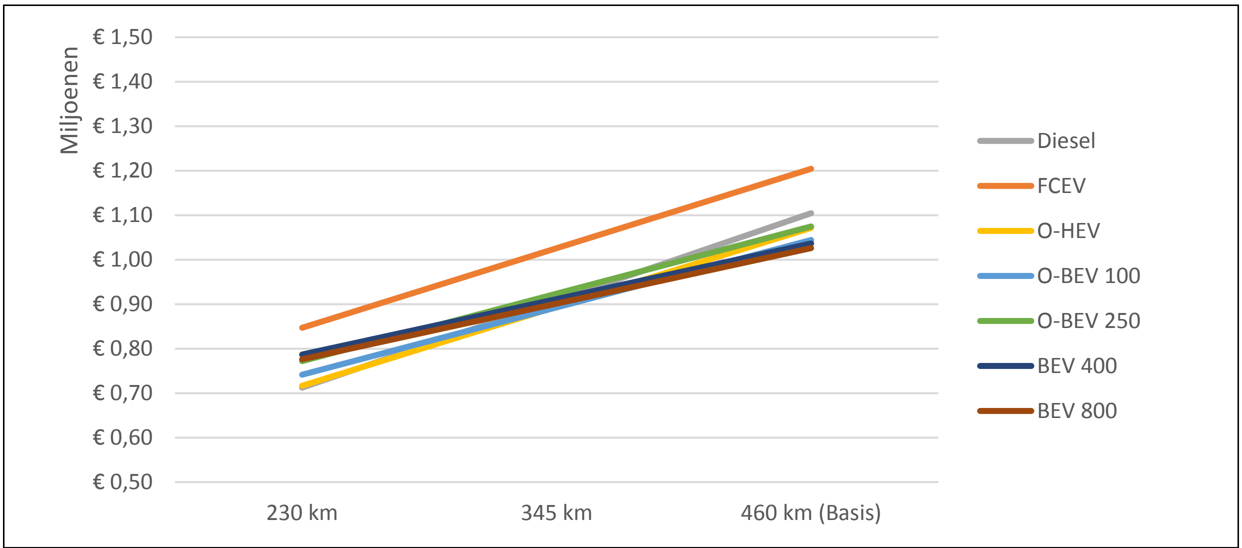
Note: the number of users for the O-BEV alternatives is still based on Movares' assumption. In the remainder of the analysis, we will discuss this in more detail for the network alternatives to be investigated, which will change the cost per user and therefore the TCO as well.

Variation in daily distances

The Movares study is based on a daily distance of 460 kilometres for a tractor-trailer. Statistics from Statistics Netherlands and, for example, research from the Port of Rotterdam[26] show that there is a wide variation in this figure. It is therefore necessary to look at different daily distances.

If we look at daily distances that are 25 percent (345 km) and 50 percent (230 km) lower, the TCO is as follows.

Figure 3.2: Sensitivity of the TCO to daily distance



It can be seen that all alternatives are sensitive to changes in the daily distance. This is logical because energy and other variable costs will then increase. A 1% change in daily distance affects the TCO of the alternatives between 0.5% and 0.7%. Not all alternatives are equally sensitive to the daily distance. The alternatives with the higher OPEX such as Diesel and O-HEV are more sensitive than the O-BEV and BEV alternatives[27].

The daily distances of the trucks are therefore taken into account in the cost-effectiveness of the ERS in the remainder of this study.

HGV toll and backstop

An HGV toll will be introduced in the Netherlands. At the moment, the debate in the House of Representatives is being prepared. The Eurovignette Directive contains the European rules for charging heavy goods vehicles for the use of infrastructure (HGV toll). The directive is currently being revised. The tariffs charged for emission-free HGVs will be lower than those of current EURO VI diesel trucks. The discount for zero-emission goods vehicles should be between 50% and 75% of the rate for EURO VI

[26] E-Trucks in de Rotterdamse haven, Port of Rotterdam, 2019

[27] Both the OPEX and the CAPEX are relatively high for the FCEV, so the cost per kilometre travelled decreases less rapidly as the daily distance increases.

vehicles. The level of the tariffs in the Dutch situation is still being determined, as is the level of the discount rates for zero-emission freight traffic.

The Movares assumptions are used in the above TCO calculation. This does not yet include a reduction in the tolls charged for zero-emission vehicles. Subsidies or the recycling of toll revenues have not yet been taken into account either. When they are taken into account, the difference between the TCO of diesel and the TCO of the zero-emission vehicles will change in favour of the zero-emission trucks. This may involve substantial sums of money. If a diesel truck pays €180,000 in tolls during its lifetime (Movares' assumption), a zero-emission truck could save €90,000 to €135,000, which amounts to more than 10 percent of the total cost. This is not expected to change the differences between range-comparable zero-emission vehicles.

3.2 Business case for transport operators: more than TCO

For transport operators, the TCO is of course important, but it is not the only factor that determines their choice of zero-emission technology. On the basis of desk research and expert interviews, we come to the following list of factors that are also of great importance to transport operators:

- A transport operator wants to be as independent of external factors as possible. With ERS, the transport operator is dependent on political decisions (the construction of the ERS infrastructure) and long-term contracts with freight forwarders (freight on the routes where ERS is present). If there is any doubt about either of the two, O-BEV trucks will not be the first choice.
- Transport operators, especially the smaller ones, want as homogeneous a fleet as possible for reasons of operational versatility. This is less of an issue for major transport operators, as they can easily allocate different trucks to different types of journeys. But for them, homogeneity of the fleet produces economies of scale. Having too many O-BEVs (and to a lesser extent BEVs) in the fleet reduces flexibility.
- If trucks are to be matched to routes, a critical mass of ERS routes is needed, as well as fixed logistics patterns (trucks always travelling the same routes).
- Therefore, in the early stages of ERS (small network), it will hardly be economically viable to operate the network profitably, the operating expenses for the transport operators becoming too high because the volumes are too low. But growth can increase exponentially with the network.
- System security is very important, as is the predictability of any work/disruptions. It is therefore essential to have a fall-back battery for emergencies.
- The ERS operator must at all times charge fair and predictable fees for using the system. Transport operators with O-BEV trucks are "locked in" and therefore want maximum certainty about charges and trends in charges.
- The supply of vehicles must be sufficiently large, and not from a single OEM, but widely distributed across the market to promote competition and confidence in investing in the future. This is certainly not yet the case at present.
- ERS technology must be proven and reliable, as a power failure will have a much bigger impact than in the case of a battery electric truck. Safety, including in relation to cable breaks, must be guaranteed.

- It helps if freight forwarders are interested in transport via ERS, for example, if they want to provide guarantees with long-term contracts or share the risks in some other way.
- Leasing companies and large transport companies as vehicle owners, including owner-drivers, have an important role to play.

The above points are mainly by way of preconditions for transport operators. O-BEVs clearly also have a number of advantages for transport operators:

- Recharging takes place on the road, so no time is lost with interim charging.
- Compared to a BEV, the truck is less heavy, so it has a greater charging capacity.
- With an O-BEV truck, the transport operator has to invest less money upfront because fewer large battery packs and less heavy charging points are needed.
- ERS can also be useful for truck recharging, for example, for trucks used in distribution transport in cities.
- The provision of charging infrastructure in cities as well as at depots is currently experiencing problems due to network congestion. If they use ERS, transport operators do not have to arrange this themselves.

In conclusion, there are many more aspects which are important to the transport operator than just the TCO. The most important of these are the reliability of the system and a network big enough to cover the most important journeys. It is therefore too simplistic to assume that transport operators will choose an O-BEV if the TCO is the most favourable. In addition, freight forwarders, OEMs and leasing companies are clearly another important factor in making ERS a success.

3.3 For which journeys is ERS an attractive option?

All in all, there are a few "calculation rules" that we can derive from the above to determine the potential demand for ERS. They are as follows:

1. Trucks have to drive at least 70% of their daily distance on the ERS route to be able to get fully charged.
2. The origin or destination must be no further than 30 km from the ERS route.
3. The trucks should have a relatively fixed driving pattern throughout the year, so that the transport operator knows it will never have to travel too far outside the ERS network.
4. The greater the daily distance, the more likely it is that the TCO of an O-BEV will be more favourable than that of a BEV. Because it is not possible to determine precisely (see 3.2) the daily distance at which the tipping point occurs, we have looked at the different minimum daily distances travelled by HGVs (from 90 km, 120 km, 150 km and 180 km).

The criteria are outlined below.

Travelling 70% of the daily distance on the ERS route

An O-BEV has to travel part of its daily distance on the ERS route in order to be able to get fully charged. This part can be calculated from the driving efficiency (1.51 kWh/km) and the maximum charging speed

(2.2 kWh/km). Outside the ERS route, the battery loses 1.51 kWh per km. On the ERS route, the battery charges at 0.69 kWh per km. To have no net energy loss (and therefore risk empty batteries), an O-BEV would have to travel about 2.19 times more km on the ERS route. This corresponds to 70% of the daily distance.

Not travelling further than 30 km from the ERS track

An O-BEV cannot travel further than 30 km from the ERS route. Due to the low battery capacity (we have assumed a battery range of 100 kilometres), it is not practical for O-BEV to travel far beyond the ERS route. With a maximum of 30 km (and 30 km return journey), the O-BEV still has a margin to allow for an unexpected situation such as a diversion. In addition, degradation of the battery and, for example, cold weather must also be taken into account. The basic principle of the O-BEVs is that they are not recharged at the depot (where they are usually left overnight).

Fixed driving pattern

Only the HGVs that travel or are capable of travelling on the ERS network all year round are potential users. Tractor units with frequently changing driving patterns are disregarded (depending on the interlinking of the network). Based on knowledge of the various logistics networks and estimates of concentrations and fixed patterns, an expert estimate was made of this use for the various network alternatives. It would be possible to obtain more certainty about this, for example on the basis of Statistics Netherlands microdata, but this is outside the scope of this project.

Minimum daily distance

One advantage that an O-BEV has over a BEV is that it does not require as much battery capacity. However, the O-BEV always needs a base battery capacity to be able to travel distances outside the ERS route. Installing a pantograph on an O-BEV costs as much as installing batteries, which increase its range by about 90 km. Routes with a daily distance of up to 120 kilometres are therefore quickly disregarded, unless the kilometre costs of an O-BEV are much lower than those of a BEV. In that case, an O-BEV can also be an attractive option for daily distances of less than 120 kilometres. Furthermore, the greater the daily distance, the greater the possible advantage of an O-BEV over a BEV. As we do not yet know when the TCO of O-BEV will become attractive, we have calculated the numbers of trucks with minimum daily distances (90 km, 120 km, 150 km and 180 km). On this basis, it is possible to estimate whether there is sufficient demand for a competitive TCO (after all, the TCO of the O-BEV is related to the use of the ERS).

Conclusion

The number of ERS users will determine the TCO of O-BEVs, and this TCO will in turn determine the number of users. To solve this chicken-and-egg problem, we have compiled a number of "calculation rules" to work out how big the demand for ERS is likely to be in different networks. In Section 4, these calculation rules are applied to the different network alternatives.

4. ERS network alternatives

Three ERS network alternatives were identified on the basis of the analyses in Sections 2 (road traffic flows and characteristics) and 3 (TCO and business case), . They are presented in this section, after which the potential use of these ERS networks has been estimated.

4.1 Three network alternatives

The literature scan showed that ERS is not cost-effective on a single corridor in other countries, especially in Sweden and Germany. This is logical, because as the network expands, a larger proportion of HGVs will be able to use ERS for a sufficiently long stretch of their journey. The road network in the Netherlands is denser than the average in many other countries and the intensities of freight traffic are also relatively high. It is therefore relevant to investigate how different types of networks work out for the Dutch situation.

Based on the insights gained from the various sources, three alternatives have been worked out:

- Alternative 1 aims to gain an insight into the effect of one strand with ERS. Based on insights into the distribution structure and HGV intensities, the A2 motorway between Amsterdam (A10 junction) and Eindhoven (Leenderheide) was chosen. This involves 125 km of carriageway (which means 250 km for ERS in two directions).
- Alternative 2 focuses on providing a "core network" with ERS. Likewise based on distribution structures and HGV intensities, a network has been developed that is mainly located in the greater Randstad area with offshoots on important main axes (Zwolle, Hengelo, Venlo). It involves 980 km of carriageway (i.e. 1,960 km of ERS in both directions).
- In alternative 3, the entire A-road network is equipped with ERS (i.e. all roads with motorway status). This road network comprises 2,500 km of carriageway (i.e. 5,000 km of ERS in both directions).

Figure 4.1: ERS network alternative 1 (left) and 2 (right)

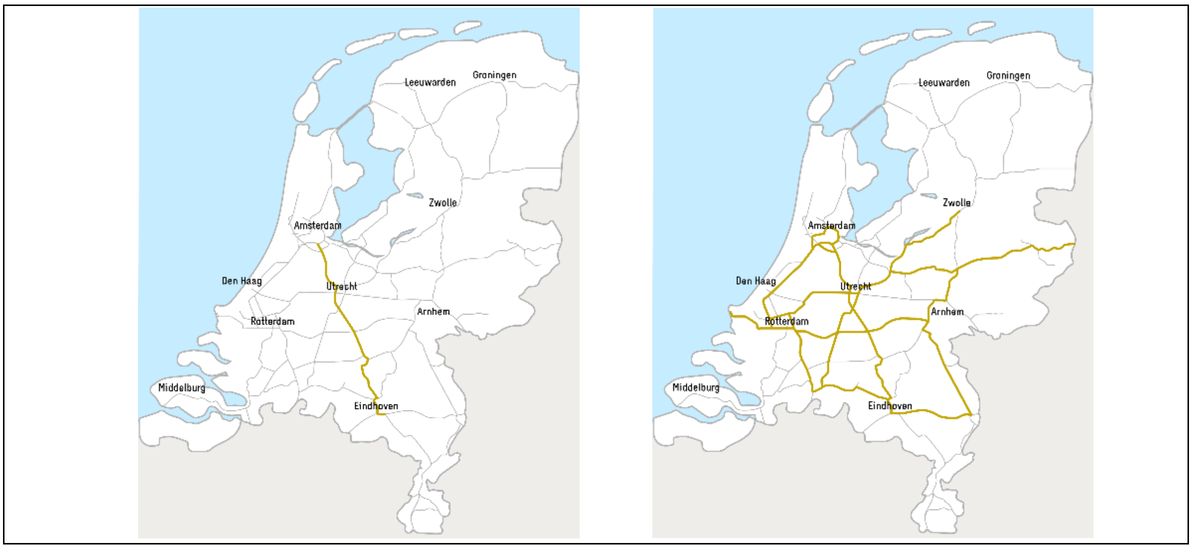


Figure 4.2: ERS network alternative 3

The capital expenditures required are listed in the table below. For this, we used the assumptions made by Movares, whereby the cost per kilometre of ERS (in both directions) is €3.3 million.

Capital expenditures on ERS network for the three alternatives

	Total capital expenditures
Alternative 1	€0.4 bn
Alternative 2	€3.1 bn
Alternative 3	€7.8 bn

4.2 Potential demand by alternative

We have estimated the potential number of vehicle-kilometres via ERS for the three network alternatives. We did this by applying the four calculation rules mentioned above.

1. Trucks have to travel at least 70% of the daily distance on the ERS route.
2. The origin or destination must be no further than 30 km from the ERS route.

3. The trucks should have a relatively fixed driving pattern throughout the year, so that the transport operator knows it will never have to travel too far outside the ERS network.
4. The greater the daily distance, the more likely it is that the TCO of travelling via ERS is more favourable than battery electric. We have looked at the trucks that meet the above two calculation rules by minimum daily distances (from 90 km, 120 km, 150 km and from 180 km).

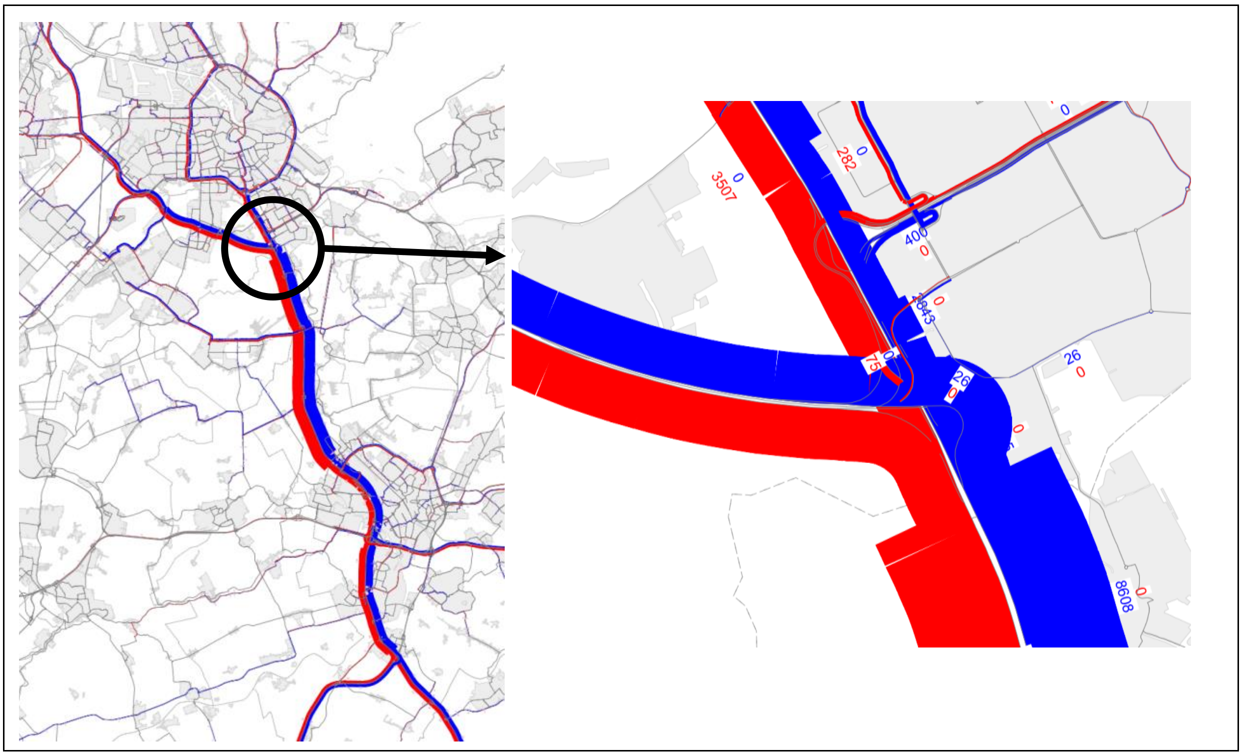
Calculation rules 1 and 2

To gain an insight into the potential use of ERS, four selected links were made in the LMS (national model system). We expect that, collectively, the freight traffic on these selected links will be reasonably representative of the traffic on the network as a whole. They are:

- A2 at Breukelen
- A4 at Roelofarendsveen
- A15 at Hardinxveld
- A50 at Heteren

The selected links show in detail how the journeys that pass through them branch off (see Figure 4.3).

Figure 4.3: Detail of structure of selected links



We applied the first two calculation rules as follows (for each of the three network alternatives):

- the length was determined of the part of the journey which can be covered by ERS. This was divided into four distance categories based on a rounded estimate (see Figure 4.1 for an example of the procedure);
- the same was done for the parts of the journey that have to be travelled without ERS, also based on a rounded estimate.

Table 4.1. Illustration of how the journeys were analysed

Alternative 2			
(West)		(East)	
Route(s) with ERS (km)	% journeys	Route(s) with ERS (km)	% journeys
<20	10	<20	0
20 – 50	70	20 – 50	10
50 -100	15	50 -100	30
>100	5	>100	60

Based on the above, we arrived at the following numbers of HGVs per 24-hour period, on average per kilometre, that satisfy the first two calculation rules. This was determined by reading off the numbers of journeys on the relevant routes from the selected links, combined with an estimate of the length of these routes.

Table 4.2. Number of trucks potentially using ERS after applying calculation rules 1 and 2, on average per kilometre per 24-hour period.

	Average ERS use per km
Alternative 1	3,721
Alternative 2	15,964
Alternative 3	9,443

It can be seen that network alternative 2 has the highest potential demand. Compared to alternative 1, this is due to the fact that many more trucks can travel 70 percent of their journey on the ERS network. The lower score of network alternative 3 is due to the fact that in alternative 3, less frequently travelled parts of the network are equipped with ERS, which means that the intensity per *average* kilometre of ERS is lower.

Calculation rule 3

Calculation rule 3 is about ascertaining what proportion of the HGVs on each of the network alternatives has such a fixed pattern during the year that the transport operator could indeed switch to an ERS truck without worrying about not being able to use the ERS network for a specific journey (i.e. travelling more than 30 kilometres one way).

Section 2.2 describes important subsectors in road transport. Among the most important subsectors, many of their journeys have fixed patterns: from production or logistics locations to distribution centres or from distribution centres to locations of regular customers or to regular retail outlets. Thus, a significant proportion of the patterns is fairly constant.

To analyse this properly, we could have used microdata from Statistics Netherlands, which annually records the pattern of a sample of individual HGVs. However, this is outside the scope of this study. Alternatively, based on the project team's expert knowledge, insights into distribution chains in subsectors and reviewing these in interviews, we have made a rough estimate of what proportion of HGVs on each of the three network alternatives travels in such a fixed pattern that the HGV could permanently cope with this ERS network.

These factors are 25, 65 and 80 percent for alternatives 1, 2 and 3, respectively (see Table 4.3).

Table 4.3. Estimate of what proportion of the trucks travels a sufficiently fixed annual pattern for ERS by network alternative

	Estimated sufficiently fixed pattern	Factor used	Average ERS use per km
Alternative 1	25-33%	25%	930
Alternative 2	65-75%	65%	10,376
Alternative 3	80-90%	80%	7,555

Calculation rule 4

Finally, based on the LMS forecasts, an estimate was made of the distribution across daily distances of the numbers of HGVs that can use ERS in each of the network alternatives. This is relevant because, as previously stated, ERS is particularly attractive for long-haul journeys.

Table 4.4. Estimate of cumulative 24-hour average demand per km for ERS with daily distance from[28]

Daily distance from	Alternative 1	Alternative 2	Alternative 3
>180 km	402	4,480	3,262
>150 km	499	5,563	4,050
>120 km	606	6,761	4,923
>90 km	758	8,458	6,158

At the same time, to make an ERS system affordable, it is important that enough HGVs use it so that the infrastructure costs can be spread over as many O-BEV kilometres as possible. Since it is impossible to estimate in advance the daily distances at which transport operators will switch to O-BEVs, this analysis shows the results of these different categories of daily distances.

In the analysis, we began by assuming that the cost of the ERS infrastructure would have to be recovered by applying a mark-up to the electricity tariff. After all, the same applies to battery-electric charging. The charger also pays for the charging infrastructure (either by having its own charging point built or by imposing a mark-up on public charging points).

[28] The figures in the table refer to WLO High by 2040. Calculations were also made for WLO Low and forecast year 2030.

4.3 Resulting TCO

Using the calculation rules, we estimated the cumulative demand for the entire ERS network for the alternatives. This is based on LMS calculations based on the WLO High scenario and forecast year 2040. WLO Low was also calculated, which we will show in subsequent sections.

Table 4.5. Estimate of cumulative demand in vehicle-kilometres (x 1,000) per 24-hour period for total ERS network with different daily distances (rounded) 2040 H

Daily distance from	Alternative 1	Alternative 2	Alternative 3
>180 km	50	4,400	8,200
>150 km	60	5,500	10,100
>120 km	80	6,600	12,300
>90 km	90	8,300	15,400

In order to find out the demand per year, the mark-up factors[29] were used to calculate annual totals. This results in the following demand by 2030:

Table 4.6 Estimated annual cumulative demand in million vehicle kilometres for total ERS network with different daily distances (rounded) 2040 H

Daily distance from	Alternative 1	Alternative 2	Alternative 3
>180 km	13	1,140	2,118
>150 km	16	1,416	2,629
>120 km	20	1,721	3,196
>90 km	25	2,152	3,998

By way of comparison: In 2018, a total of 7.2 billion kilometres were covered by HGVs (both Dutch and international) in the Netherlands. The cost of the ERS infrastructure per vehicle-kilometre was determined based on the volumes in Table 4.6.

We used the figures in the Movares study to estimate the cost of ERS per kilometre. The capital expenditures (CAPEX) and the fixed and variable management and maintenance costs (OPEX fixed and OPEX variable) were plotted over time, from 2030 to 2065. These costs have been discounted to their net present value using a discount rate of 1.6 percent. An annual growth rate of 0.16 percent (Low scenario) and 0.98 percent (High scenario) were used for ERS use (O-BEV kilometres). This growth rate is based on the difference in HGV kilometres between 2030 and 2040 as shown in LMS projections. We took the weighted average of the variation in number of journeys in the L3 category and the HGV part of the L2 category. In order to calculate the infrastructure cost per kilometre travelled, which is reflected in the TCO, we assumed a break-even scenario over a period of 35 years. The cost price is therefore calculated by dividing the total cost by the kilometres travelled (converted to kilowatts charged, which are then factored into the electricity price).

Figure 4.4 shows a recalculation of the TCO based on the calculated ERS costs per kilometre travelled, i.e. the total cost of operating an HGV over its lifetime.

[29] Ophoogfactoren Rijkswaterstaat WVL, opgesteld door 4Cast (2021)

The graph compares medium- and long-haul O-BEVs and BEVs for network alternatives 2 and 3. For medium distances, the O-BEV 100 and 75 are compared to the BEV 200. For long distance, the O-BEV 150 is compared to the BEV 400 and 800.

The TCO of the O-BEV varies with the number of HGVs using the ERS. The graph shows what the TCO of the O-BEV is if HGVs with certain minimum daily distances (that meet the calculation rules) use ERS. The TCO is most favourable when HGVs with daily distances of 90 km or more use ERS, because the use of ERS is highest then. The TCO becomes less favourable as fewer HGVs use ERS. The HGVs with the shorter daily distances are the first to be disregarded, as an O-BEV is more advantageous than a BEV as the daily distances increase.

Figure 4.4. Comparison of the TCO of medium- and long-haul O-BEVs and BEVs for different HGV volumes using ERS (TCO in MEUR over lifetime of HGV)[30]

[30] The TCO calculations are, as is usually the case, presented as total costs over the lifetime of the truck. An alternative is to present the TCO costs per kilometre. In that case, the ratio of BEVs to O-BEVs would not change. What would change is that the cost per kilometre for long-haul transport would become lower than for medium-distance transport. This is because the (higher) fixed costs are spread over more kilometres, reducing the total cost per kilometre.

The graph compares the TCO of the O-BEVs with the comparable BEVs for the three alternatives and for both medium-haul (blue bars) and long-haul transport (yellow). It can be seen from the graph that alternative 1 shows an unfavourable O-BEV TCO compared to the BEV alternatives in all cases. For alternatives 2 and 3, the O-BEV TCO is lower than the BEV TCO in all situations and therefore favourable. This applies even if only the HGVs with a daily distance of over 180 kilometres use the ERS.

The above calculation does not yet take into account the start-up losses that will be incurred by an ERS because the construction will take a number of years, and the start-up will also take time. We will come back to this in the next section.

4.4 ERS can accommodate demand in a cost-effective way

The assumption made in the Movares study was that the voltage on the ERS system would be 600 volts, as in the German pilots. A higher voltage is also possible, but this is less clear-cut and was not elaborated on by Movares. Assuming one rectifier station every 2 kilometres and accepting the other assumptions made by Movares, there is 2.2 kWh/km of electricity available per kilometre of ERS (for both directions) for four O-BEVs. If fewer than four O-BEVs are connected, more is available. If more vehicles are on the road, less electricity is available. On average, 1.51 kWh/km is needed to drive a vehicle. Any additional power available can be used to charge the battery.

The key question is of course how many trucks can use ERS and how this relates to the numbers in the TCO calculations we presented. We carry out a simple check on this below.

The base for the calculations consisted of the following numbers of O-BEVs using the system, on average per kilometre of ERS, per 24-hour period, at certain minimum daily distances. For clarification: The ">150" line shows the numbers of ERS users per kilometre per hour if all trucks with daily distances above 150 kilometres that comply with the calculation rules use ERS. Therefore, as the minimum daily distance decreases, the usage increases.

Table 4.5. Cumulative 24-hour demand per linear km of ERS with minimum daily distance from:

Cumulative demand per km of ERS with daily distance from:	Alternative 1	Alternative 2	Alternative 3
>180	402	4,480	3,262
>150	499	5,563	4,050
>120	606	6,761	4,923
>90	758	8,458	6,158

The table below shows an indicative calculation of the maximum number of O-BEVs that can use the ERS per 24-hour period. This number is about 3,600 at the current grid level, with the associated capital expenditures. This means that capacity in alternatives 2 and 3 is no longer sufficient if HGVs with lower daily distances also use ERS.

We have calculated that with an average use of around 2,000 HGVs per 24-hour period, the TCO of an O-BEV will be approximately the same as that of a BEV for medium-haul transport. So if demand is managed, the TCO can remain positive in any event. Incidentally, capacity on certain sections of the network can be increased relatively easily and cost-effectively by building more rectifier stations and using heavier cables[31].

Maximum number of O-BEVs per kilometre of ERS network

Number of trucks that can charge at the same time per kilometre	4	
Average speed	90[32]	km/h
How long does a truck take to drive a kilometre?	0.67	minutes
How many trucks can use those ERS kilometres in an hour?	360	
Factor: hours/day	10	
Therefore maximum per day	3,600	

4.5 Conclusion: Alternative 1 not profitable, alternatives 2 and 3 profitable under certain conditions

In this section, we have seen that the calculated TCO of O-BEV trucks is not competitive for network alternative 1, but is competitive for network alternatives 2 and 3. This is the case even if only trucks with a daily distance of 180 kilometres will use the system (for journeys that meet the calculation rules). We have also seen that the capacity of the ERS system is not an obstacle to achieving a cost-effective TCO.

We have not yet taken into account the start-up losses and other social impacts of ERS. These are discussed in the next section. As alternative 1 is not an attractive option, we will disregard it in the rest of the report.

[31] This will be discussed in greater detail in Section 5.5.

[32] Although the speed limit on motorways for freight traffic is 80 km/h, the actual speed is somewhat higher. In this calculation example, we have assumed 90 km/h.

5. Social impact

5.1 Capital expenditures and operating expenses of the network

The capital expenditures (CAPEX) for the ERS network consist of costs for components such as overhead line, rectifier stations, control and monitoring system and individual connections. The fixed operating expenses (OPEX fixed) consist of the fixed maintenance costs and the variable operating expenses (OPEX variable) consist of electricity costs and replacement due to abrasion of the overhead line. The figures below were used to calculate the costs: CAPEX EUR 3.3 million per kilometre, OPEX fixed EUR 3.7 million per kilometre over lifetime and OPEX variable EUR 0.19 per vehicle-kilometre, see also Table 5.1.

Table 5.1 CAPEX and OPEX (fixed and variable) overview

Cost type	Cost	Unit	Source
CAPEX	€3.3	MEUR per km	Movares (2020)
OPEX fixed	€3.7	MEUR per km over lifetime	Movares (2020)
OPEX variable	€0.19	EUR per vehicle-kilometre	Movares (2020), PBL (2021) and EVConsult (2021)

The total cost is an aggregation of the aforementioned cost types. In order to determine them, the total kilometres of the network alternatives were used, a 35-year lifetime of the ERS network was assumed (as per Movares), the annual demand per alternative for ERS was estimated for the WLO High and Low scenarios. A discount rate of 1.6% was used to discount all costs[33]. In addition, an annual growth in demand for ERS has been taken into account according to the following percentages; 0.98% for WLO High and 0.16% for WLO Low. We determined these percentages by taking the growth in the number of journeys between 2030 and 2040 (and 2050) as used in the LMS. We used the weighted average of categories L3 and L2 (HGV part).

The costs were plotted per year over time and discounted to the year construction begins: 2030. Alternatives 1 and 2 are constructed in five years, while alternative 3 is constructed in seven years.

Table 5.2 Total cost of ERS network alternatives for 35 years in millions of euros, price level 2030

	WLO High	CAPEX	OPEX fixed	OPEX variable	Total cost
Alternative 2	Daily distance > 180 km	€3,137	€257	€5,800	**€9,194**
	Daily distance > 150 km	€3,137	€257	€7,202	**€10,596**
	Daily distance > 120 km	€3,137	€257	€8,753	**€12,147**
	Daily distance > 90 km	€3,137	€257	€10,950	**€14,343**
	Daily distance > 180 km	€7,879	€630	€10,656	**€19,165**

33 https://www.rwseconomie.nl/discontovoet

	WLO High	CAPEX	OPEX fixed	OPEX variable	Total cost
Alternative 3	Daily distance > 150 km	€7,879	€630	€13,231	**€21,740**
	Daily distance > 120 km	€7,879	€630	€16,081	**€24,590**
	Daily distance > 90 km	€7,879	€630	€20,116	**€28,625**
	WLO Low	CAPEX	OPEX fixed	OPEX variable	Total cost
Alternative 2	Daily distance > 180 km	€3,137	€257	€4,551	**€7,945**
	Daily distance > 150 km	€3,137	€257	€5,650	**€9,044**
	Daily distance > 120 km	€3,137	€257	€6,867	**€10,261**
	Daily distance > 90 km	€3,137	€257	€8,591	**€11,985**
Alternative 3	Daily distance > 180 km	€7,879	€630	€8,349	**€16,858**
	Daily distance > 150 km	€7,879	€630	€10,366	**€18,875**
	Daily distance > 120 km	€7,879	€630	€12,599	**€21,108**
	Daily distance > 90 km	€7,879	€630	€15,761	**€24,270**

The table clearly shows that capital expenditures increase with network size and that variable costs and therefore total cost increase with usage. The costs are highest if the appropriate HGVs with daily distances of over 90 kilometres also use ERS.

5.2 ERS start-up losses

There will be an assimilation of ERS use after the first ERS corridors are built, which means that the ERS system will not be used to its full potential immediately. This will affect revenues over the first few years.

The start-up rate of ERS use is also based on the depreciation period for diesel vehicles. This depreciation period is seven years on average.[34] To calculate the effect of this assimilation, we have assumed that ERS is not used for the first three years of the construction period. Thereafter, the use of ERS grows by 1/7 per year until the 100 percent demand expected in year 10.

This means that a mark-up will have to be applied to the selling price of electricity, at least if these "start-up" losses are to be recovered. This has been worked out in the table below, and the "lost sales" have been calculated. In total, WLO High accounts for over 9 percent of the total cost and WLO Low accounts for over 6 percent.

[34] https://www.evofenedex.nl/sites/default/files/2019-08/Rapport_Kostenontwikkeling_2018.pdf

Table 5.3. Assimilation effect as a percentage of total cost

WLO High: assimilation effect		Difference in selling price of energy due to assimilation €/kWh	"Lost sales" (MEUR)
Alternative 2	Daily distance > 180 km	€0.005	322.5
	Daily distance > 150 km	€0.004	322.5
	Daily distance > 120 km	€0.003	322.5
	Daily distance > 90 km	€0.003	322.5
Alternative 3	Daily distance > 180 km	€0.006	710.5
	Daily distance > 150 km	€0.005	710.5
	Daily distance > 120 km	€0.004	710.5
	Daily distance > 90 km	€0.003	710.5

WLO Low: assimilation effect		Difference in selling price of energy due to assimilation €/kWh	"Lost sales" (MEUR)
Alternative 2	Daily distance > 180 km	€0.005	263.5
	Daily distance > 150 km	€0.004	263.5
	Daily distance > 120 km	€0.003	263.5
	Daily distance > 90 km	€0.003	263.5
Alternative 3	Daily distance > 180 km	€0.006	573.0
	Daily distance > 150 km	€0.005	573.0
	Daily distance > 120 km	€0.004	573.0
	Daily distance > 90 km	€0.003	573.0

The lost sales or start-up losses are the same for all demand volumes (daily distances). This is because the user charge is adjusted for volume so that sales are the same as the total cost.

5.3 TCO including start-up losses still attractive

Taking into account the effect of scaling up and the associated start-up losses, a new TCO has been calculated for the three alternatives with the WLO High and Low scenarios. The basic assumption is that the start-up losses will be recouped via a mark-up during the ERS operational phase.

Table 5.4 TCO of O-BEVs with assimilation effects, WLO High

WLO H with assimilation effect			TCO O-BEV 75		O-BEV 100		O-BEV 150
Alternative 2	Daily distance > 180 km	€	600,000	€	610,000	€	830,000
	Daily distance > 150 km	€	590,000	€	600,000	€	800,000
	Daily distance > 120 km	€	580,000	€	590,000	€	780,000
	Daily distance > 90 km	€	570,000	€	580,000	€	770,000
Alternative 3	Daily distance > 180 km	€	630,000	€	640,000	€	870,000
	Daily distance > 150 km	€	610,000	€	620,000	€	840,000
	Daily distance > 120 km	€	600,000	€	600,000	€	810,000
	Daily distance > 90 km	€	580,000	€	590,000	€	790,000

By way of comparison, the BEV TCO is: 200 = €630,000; 400 = €890,000; 800 = €1,000,000.

The TCO is of course somewhat higher, but remains generally lower than for the BEV alternatives in WLO high. Only in alternative 3 does the TCO of O-BEV 100 become less favourable compared to the BEV 200 if only HGVs with a daily distance of above 180 km use the ERS. That is why that box in the table is red.

Table 5.5 TCO of O-BEVs with assimilation effects, WLO Low

WLO L with assimilation effect			TCO O-BEV 75		O-BEV 100		O-BEV 150
Alternative 2	Daily distance > 180 km	€	620,000	€	630,000	€	860,000
	Daily distance > 150 km	€	600,000	€	610,000	€	830,000
	Daily distance > 120 km	€	590,000	€	600,000	€	810,000
	Daily distance > 90 km	€	580,000	€	590,000	€	780,000
Alternative 3	Daily distance > 180 km	€	650,000	€	660,000	€	910,000
	Daily distance > 150 km	€	630,000	€	640,000	€	870,000
	Daily distance > 120 km	€	610,000	€	620,000	€	840,000
	Daily distance > 90 km	€	600,000	€	600,000	€	810,000

By way of comparison, the BEV TCO is: 200 = €630,000; 400 = €890,000; 800 = €1,000,000.

In WLO Low, in alternative 2, all O-BEV TCO calculations with assimilation remain more favourable than (or as favourable as) their BEV competitor. In alternative 3, the O-BEV 100 loses its TCO advantage over the BEV 200 if only tractor units with a daily distance over 150 km use ERS. For the O-BEV 75 this is as from 180 km daily distance (the red boxes). The other TCO calculations remain competitive.[35]

35 For a graphic representation of the comparisons between BEV and O-BEV TCO calculations for the different alternatives and scenarios, see Appendix 1.

5.4 Nuisance from ERS construction is tolerable

The construction of ERS infrastructure is relatively simple and, in any case, it seems clear that no lengthy and drastic road closures are necessary. Experience from Germany with the ELISA pilot site shows that it is sufficient to close one lane and the work can take place at night.
The first question is whether it is at all necessary to close all or parts of roads, especially for the installation of overhead line structures and rectifier stations. After all, the work will obviously be combined with regular maintenance of the asphalt on the right-hand lane. This happens once every seven years in any case. Coordinated planning means that work can be combined. In the best-case scenario, the maintenance and installation of the ERS system will take place at the same time, so there will be no additional disruption to road traffic.

In a less favourable case, the construction of the ERS infrastructure does require the closure of all or parts of roads because it is not possible to combine this with maintenance work. Or the construction of the ERS infrastructure means that lanes have to be closed for a prolonged period of time.

We have made a simple calculation to get a feel for the order of magnitude of the social impact if lanes have to be closed at night to build ERS infrastructure. We arrive at social costs of about EUR 600,000 (alternative 1) to EUR 4.5 million (alternative 2) to EUR 11.5 million (alternative 3).[36] Compared to the other infrastructure costs, these effects can be described as marginal.

One concern is that the inconvenience during construction would not be limited to delays for road traffic. The construction of energy infrastructure to the motorways, for example, may also cause inconvenience. The exact nature of this inconvenience will be the subject of further research when there is more clarity about the way in which the ERS structure will be constructed.

5.5 Still a lack of clarity about capital expenditures in the deep electricity network

The capital expenditures on the electricity network are obviously of great importance when deciding on the possible construction of an ERS network. As in the Movares study, in this study we have assumed that a rectifier station must be built every 2 kilometres or so and connected to the medium-voltage network. The connection costs and the cost of the required cables are as assumed by Movares.

Movares also showed that if the demand for ERS increases, the capacity of the ERS network can be scaled up by increasing the number of rectifier stations and making the cables thicker. In this case, the costs increase less than proportionally to the number of HGVs that can be charged. In principle, therefore, the TCO becomes more favourable if, due to high demand, heavier connections are chosen.

A major concern, however, is the investment in the "deeper" electricity network required for ERS. This applies to both the high-voltage and the medium-voltage network. In view of all the changes that the energy

[36] Assumptions for these calculations: road closures for ERS: 2 nights at 6 hours per kilometre, average speed goes from 120 km/h to 70 km/h, average intensity 577 vehicles/hour, journey time valuation according to specified key figures.

transition will make to the supply of and demand for electricity in the coming years and decades, it is essential to invest heavily in the electricity network. This is necessary to connect all the new energy sources, both offshore and onshore, and also to meet the rapidly growing demand for electricity from households, industry and the mobility sector. The association of the Netherlands' network operators, Netbeheer Nederland[37], has developed four scenarios which, depending on trends on the demand and supply side, justify a substantial investment in the electricity network in particular. PWC has calculated that the capital expenditures required for the necessary network expansions will amount to at least EUR 1.5 billion per year for the next 20 years[38]. However, the exact choices of investment have not yet been made, although it is clear that the network will be reinforced in all regions and that offshore wind will be an important factor in the expansion.

The possible construction of ERS will undoubtedly contribute to a need for additional investment in the deeper electricity network. But this also has to be done in a scenario involving BEV trucks, because all the charging stations, and in particular rapid charging stations, will also take up a lot of the available capacity. With the information we have at the moment, it is therefore impossible to say in advance what additional capital expenditures will be required for the deeper network. This is also confirmed by the E-Laad foundation.

However, it is safe to say that ERS has the disadvantage, compared to a BEV scenario, of requiring more peak power. It must be possible to supply ERS vehicles with the maximum power. Charging, especially at night, places a much lower demand on capacity but the reverse is true for rapid chargers. The peak power they require is considerably higher. A point in ERS's favour may be that the peak demand is at times when there is an ample supply of solar energy (especially in summer).

Furthermore, the capital expenditures on ERS are higher because many additional cables have to be laid along motorways. However, these capital costs (connection to mid stations) have been included in this study, as well as in the TCO calculations.

In Germany, the impact on the electricity network has already been examined in more detail[39]. Researchers looked at the impact of an ambitious roll-out of ERS in Baden-Württemberg. The conclusion of this study was that the total electricity demand would increase by 8 percent in this area but there were outliers of more than 30 percent in sparsely populated areas. The researchers rightly say that peak demand, which can be 3.5 times higher than average demand, has to be taken into account. This study also states that the peak demand does coincide with the periods when a relatively large amount of solar energy is being generated in the region (at least in the summer period).
This is therefore a point that needs to be explored further.

[37] Netbeheer Nederland. Het Energiesysteem van de Toekomst, Integrale Infrastructuurverkenning 2030 -2050. April 2021
[38] PWC. De energietransitie en de financiële impact voor netbeheerders. April 2021
[39] Fraunhofer Institute. John Fritz, Daniel Speth, Patrick Plötz (2020). Overhead catenary vehicles in south-west Germany? A regional catenary vehicle network and its implications for electricity demand.

5.6 Carbon emission reduction by up to one third possible

The implementation of an ERS system will have an impact on road freight transport emissions. The main effect, of course, is to reduce carbon emissions as diesel HGVs in particular switch to using electricity. In addition, there are also emissions related to the ERS infrastructure and the life cycle of batteries. In this section, we first determine the carbon savings to be achieved by transport. We then look at the emissions associated with batteries and the ERS infrastructure: the LCA (life cycle analysis) concept.

5.6.1 ERS can significantly reduce carbon emissions

The extent to which an ERS system helps to reducing carbon emissions depends in particular on the speed of penetration of battery electric HGVs. The battery electric HGVs expected by 2040 are mainly lighter rigid trucks travelling relatively short distances[40]. ERS is particularly attractive for HGVs travelling longer distances. For the time being, therefore, the two techniques are complementary rather than substitutes. In addition, the savings in emissions will depend on how electricity is generated in future. In this analysis, we assume that ERS will mainly "electrify" transport that is currently effected by diesel trucks.

For this purpose, we have used key figures from the PBL (2020). They expect that emissions (in grams of carbon per km) will be 664 for trucks in a Low scenario and 645 in a high scenario by 2030. These key figures are applied to the total number of vehicle-kilometres for each network alternative and WLO scenario.

Table 5.6 shows the calculation for alternative 3. We calculated the carbon savings from the moment the ERS system is fully utilised (2040), based on the expected vehicle emissions and electricity mix by 2030.

Table 5.6 ERS carbon savings by 2040, ERS alternative 3

Alternative 3 2030	WLO High	WLO Low
Total kilometres of freight traffic in the Netherlands (billions)[41]	8.1	7.5
Kilometres of ERS (daily distances > 90 km)	3.7	3.2
Share of ERS kilometres of total	46%	43%
Carbon emissions: gram per kilometre	645	664
Total emissions (*1000 tonnes)	5,225	4,980
Saving in carbon ERS/diesel[42]	73%	73%
Total carbon savings (*1000 tonnes)	1,734	1,544
As a percentage of alternative 3	33%	31%

The kilometres travelled by freight traffic via ERS is 46% (in WLO Low 43%) of the total. The carbon savings of an O-BEV compared to diesel per KW/h in 2030 is 73%[43]. Thus, we calculate the total savings at 1.7 megatonnes of carbon (1.5 in WLO low). That is 33 and 31 percent respectively of the total carbon emissions from road transport by 2030.

40 https://publications.tno.nl/publication/34638886/arUkqJ/TNO-2021-R11987.pdf
41 PBL/CPB 2016
42 Movares 2020. By 2030, diesel delivers 329 grams of carbon per KW/h, an O-BEV 90 grams. Therefore a 73% saving.
43 Because by 2030 the electricity mix will still be partly generated from fossil fuels

Table 5.7. Saving in carbon emissions by 2030 in all alternatives

	High		Low	
	Carbon saved (tonnes)	As a percentage of road transport emissions	Carbon saved (tonnes)	As a percentage of road transport emissions
Alternative 1	11	0.2%	9	0.2%
Alternative 2	937	18%	820	16%
Alternative 3	1,734	33%	1,544	31%

For alternative 2, this percentage is 18 for High and 12 for Low. For alternative 1, the percentage saving is 0.2 percent in both High and Low.

In alternative 2, between 58 (WLO Low) and 72 (WLO High) percent of the CAPEX is recouped through carbon savings. For alternative 3, the figure is between 43 and 53 percent. The KEV (2021) projection of the carbon price for EU (ETS) by 2030 is used to express the emissions in terms of present value. This amounts to €62.00 per tonne of carbon. Relative to the total investment, alternative 2 is the most favourable in terms of carbon savings.

5.6.2 O-BEV or BEV: minor differences in well-to-wheel

To ascertain the environmental impact of ERS compared to the battery electric alternative, two concepts have to be examined: WTW emissions and Life Cycle Analysis (LCA). In the Movares report (2020), a comparison was made between the WTW emissions from BEV and O-BEV. This resulted in the following figures: For O-BEV, these emissions are 136 g/vkm and for BEV 128 g/km. The WTW emissions from these two technologies are therefore close to each other.

5.6.3 ERS or batteries: From a life cycle analysis point of view, ERS is more favourable

There is also a carbon impact arising from the manufacture and construction of the infrastructure needed (for ERS overhead lines and cables and the charging infrastructure for BEV). To find out what it is, we searched the literature for life cycle analyses (LCA).

R. Balieu et al (2019)[44] compared the environmental impact of ERS infrastructure systems. The catenary system with pantograph was compared to induction and to rails in asphalt. The outcome was that the environmental impact of the overhead line infrastructure was 140 CO_2 (tonne/FU). This is higher than the induction and rail alternatives, due to the amount of copper (cable) and steel (suspension systems) used. An FU (Functional Unit) here is 1 km of road network with a lifetime of 20 years.

Marmiroli et al (2019)[45] investigated the construction and maintenance of ERS infrastructure and, supplementing Balieu et al., also looked at the impact of wear and the maintenance of the binder layer. Using the same FU as the study by Balieu et al, they arrived at an impact from production, transport and construction of 168 CO_2 (tonnes/FU) for ERS with overhead lines. In addition, the impact of wear and tear maintenance (every 2 years) amounts to 248 CO_2 (tonnes/FU). And then there is the impact of wear and

[44] R. Balieu, F. Chen & N. Kringos (2019) Life cycle sustainability assessment of electrified road systems, Road Materials and Pavement Design, 20:sup1, S19-S33, DOI: 10.1080/14680629.2019.1588771
[45] https://www.mdpi.com/2076-3417/9/15/3117

maintenance of the binder layer of 57 CO_2 (tonnes/FU). This results in a total environmental impact of 474 CO_2 (tonnes/FU).

Translated into the three ERS network alternatives, the above studies produce the results in the table below

Table 5.8 Environmental impacts of the network alternatives

Alterna-tive	Kilometres of road surface	Balieu (2019) environmen-tal impact in tonnes of CO_2	Balieu (2019) environmental impact per vkm in grams of CO_2	Marmiroli (2019) environmental impact in tonnes of CO_2	Marmiroli (2019) environmental impact per vkm in grams of CO_2	CO_2 emissions from trucks by 2030, grams per vkm
1	125	17,500	52	59,250	175	645 – 664
2	980	137,200	5	464,520	16	645 – 664
3	2500	350,000	6	1,185,000	22	645 – 664

There are of course LCA studies on the carbon impact of batteries. D. Burul et al (2021)[46] specifically studied battery electric freight transport. The table below shows the impact of the production, maintenance and repair of HGV batteries. Their FU is the total number of vehicle-kilometres over the lifetime of the battery (500,000 km) with an average charge. This gives the following results in CO_2 (tonnes/FU). These results were then used to calculate the outcomes in terms of CO_2 (grams/vkm):

Vehicle	Production	Maintenance	Repair	Environmental impact per vkm in grams of CO_2
BEV (EU baseline)	53.6	2.4	2.1	116

The International Transport Forum, commissioned by the OECD (2021)[47], has also compared the LCAs of battery electric trucks. They used the same FU, but for different distance classes. The impact is shown as CO_2 (tonne/FU). The results were then calculated in terms of CO_2 (grams/vkm):

Vehicle	Annual vkm	Depreciation period	Production	Battery	Environmental impact per vkm in grams of CO_2
Heavy Truck BEV-500	90,000	7	47.3	18.9	105
Medium Truck BEV-300	50,000	9	16.9	16.9	75

Unfortunately, we could not include all the relevant aspects in this analysis, such as the material for charging stations, the (smaller) batteries of O-BEVs and the vehicle modifications (pantograph). Nevertheless, based on the above studies, we can conclude that the infrastructure of ERS most likely has a smaller carbon footprint than the infrastructure/battery needed for a BEV.
This LCA impact is much smaller than the emissions from the actual transport, but certainly not negligible for BEVs.

[46] https://www.scania.com/content/dam/group/press-and-media/press-releases/documents/Scania-Life-cycle-assessment-of-distribution-vehicles.pdf
[47] https://www.itf-oecd.org/sites/default/files/docs/cleaner-vehicles-technology-transition.pdf

5.6.4 Abrasion of contact wire and pantograph

Movares has already established that the greatest environmental impact of ERS is caused by the abrasion of the contact wire (copper) and pantograph slipper (carbon). Movares states that the emission of copper in particular is environmentally harmful due to its toxic properties. According to Movares, over the entire lifetime of the ERS (35 years), 1,000 kg of abraded copper per kilometre ends up on the road and in the environment.

We could not find any further research on this and our interview partners were unable to provide any information on it either. This therefore remains an impact to be studied.

5.7 Safety risks appear to be manageable

In terms of safety, there are impacts resulting from modifications to the carriageway, the risk of a wire break and the fact that ERS is likely to make it impossible for a trauma helicopter to land on the road. These aspects are set out below.

Modifications to the carriageway

The masts for the ERS wiring will in most cases be installed within the obstacle-free zone along the road. To prevent collisions, this means that guide rails will have to be installed along the roads on the outside of the hard shoulder. A large part of the road network already has guard rails, but a substantial part does not yet have them on the outside of the carriageway. Guard rails completely eliminate the risk of collision.

The road layout changes due to the installation of the ERS masts. It is expected that road users will quickly get used to the presence of the masts, so that safety will not be adversely affected. In some cases, the masts may obstruct the view over longer distances in curves. This obstruction could be reduced by increasing the distance from the mast to the roadside (longer support arms required).

The ERS infrastructure could adversely affect the readability of road signs. This aspect was also brought to light in the test track in Germany and resolved by adjusting the signs. Further research is required to ascertain how this adverse effect can be minimised for the Dutch situation.
Tunnels and viaducts do not pose a specific problem because the ERS line can be interrupted. The HGVs then drive for a while on their own battery.

Risk of wire break

The risk of wire break depends on the thickness and strength of the wire, the suspension construction, the quality of the pantographs and external factors such as vehicles which are too high. The use of overhead wires is substantially more intensive than is the case with trains, trams and trolleybuses. In addition, public transport pantographs are part of a more or less closed system, where the management of the infrastructure and the vehicles is either in the same hands or undertaken by parties in close contact with each other (such as train operators and infrastructure maintenance companies). This will be different with ERS: transport operators are not organisationally linked to the party providing the infrastructure. Inspection and certification can ensure that the pantographs meet the specified safety requirements. Aspects such as overdue maintenance or incorrect driving behaviour can, however, have a negative impact on the overhead line.

In case of a wire break, it depends on how the system is constructed whether the wire falls on the road surface or hits vehicles. In fact, this will inevitably happen. The danger from contact with electricity can be greatly reduced by detecting a wire break in the rectifier station and immediately shutting off the power. The risk of physical impact of vehicles with the wire cannot be ruled out. We do not know of any research to ascertain the severity of this impact. The situation is quite similar to that of trolleybuses and trams in urban areas, where vehicles also drive under the wires and wire breaks are bound to happen. In ERS, however, the risk seems to be higher due to the above-mentioned characteristics of use combined with the higher driving speeds (compared to urban areas). In addition to the physical impact of a wire break, it could startle drivers, which could also give rise to collision risks.

In an interview with an employee of BAST (the German Public Works Department), it was stated that the expectation is that the system can be designed to ensure that, in the event of a wire break, the cable will be arrested and not end up on the road. This seems to solve the problem.

Trauma helicopter

The wiring of ERS will prevent a trauma helicopter from landing. It is expected that this method of assistance will continue to be used in future. Alternative facilities will therefore be required for landing the helicopter, for example, in the form of roadside landing areas at regular intervals.

5.8 The impact on the landscape varies according to location

The image-defining elements of the ERS system

The ERS system is based on overhead lines above motorways. The overhead lines are laid in both directions and are similar in appearance to the overhead lines used on railways. Technical installations such as rectifier stations are also needed every 2 kilometres. In the pilots already carried out, these stations are the size of a sea container.

Open and enclosed landscape

In this study, we assume three network alternatives. The motorways used in all the alternatives cross different landscape types. The extent of any impact on spatial quality at regional scale depends on the openness of the landscape. This determines how visible the ERS system will be. At the present stage of this study, it is sufficient to distinguish between open and enclosed and semi-enclosed landscapes, as outlined below:

- open landscapes: peat meadow areas in the west of the Netherlands, polders in the west and north of the Netherlands and the river landscape in the centre of the Netherlands
- enclosed and semi-enclosed landscapes: wooded areas in the centre of the Netherlands, urban areas and the varied landscape (semi-enclosed) of the high sandy plains in the south and east of the Netherlands

Impact on spatial quality

From the road user's point of view: the ERS system has an adverse impact on spatial quality. For the road user, it creates a messier and more crowded street scene, regardless of the type of environment.

From the surrounding landscape: generally speaking, the ERS system has an adverse impact on spatial quality when viewed from the surrounding area. It crosses the landscape and is visible to a greater or lesser extent to users of the landscape (recreation, housing, mobility, etc.). The subtle difference between an open and a enclosed landscape is very important here.

The adverse impact of an ERS system on the surrounding area will be greatest in the open landscape. It cuts through the empty open spaces and is visible from a great distance 24 hours a day. The change in the landscape will be greatest along roads where there are currently no light poles.

In wooded areas, near motorways with many noise barriers (screens and walls) and in urban areas, the impact on the surrounding area will be the smallest. After all, in these cases the ERS system is shielded to a greater or lesser extent by various upright elements such as buildings and planted areas.

5.9 Labour market: where are scarce labour resources most needed?

The situation on the labour market also has to be considered. At present, there is a major shortage of the workers needed for the energy transition. This is evident from, among other things, the Dutch government's climate policy dashboard[48]. There are major shortages in the electricity sector in particular. In this sector, 26 occupations have been described as being required immediately for the implementation of climate policy. Most of them are technical trades. The majority of these trades face a very tight labour market. By way of illustration, there were 4,600 vacancies for electricians and electrical fitters in Q2 2021. But the labour market is also tight in the wider construction sector.

This shortage is expected to continue for the next few years, given the major challenges in the field of energy and because opportunities for rapid growth in this occupational group are limited. PBL has made a scenario study of the impact on the labour market of the energy transition up to 2030[49]. This shows that there will be an increasing demand for labour in the coming years, even if expenditure by businesses, government and households remains unchanged. And this increasing demand will be greater than the number of job-seekers, thereby increasing the tension on the labour market. The PBL also concludes that the choice of certain technologies has an impact on labour shortages: *"If the demand for electrical plant or machinery increases as a result, the tension will increase more than if there were a greater need for labour from the construction industry and business services. Increasing the production of electrical plant and machinery requires more workers with a technical background and only a small proportion of job-seekers have this*".

48 https://dashboardklimaatbeleid.nl/jive/jivereportcontents.ashx?report=arbeidsmarkt_en_scholing

49 Netherlands Environmental Assessment Agency, September 2020, Regionale arbeidsmarkteffecten van de energietransitie: een scenarioverkenning..

When it comes to making road transport more sustainable, both ERS and the installation of rapid charging points for BEVs will require a lot of labour resources to make this possible. In some respects, this is the same type of labour and in others it is not, because a large part of the work in the construction of the ERS network tends more towards the civil engineering sector. But there are shortages in this sector, too.

Clearly, building an ERS network requires a larger investment than building a network of charging points and it is therefore to be expected that the labour resources required are also larger. Further research is required to ascertain whether this also applies to labour resources in the electrical engineering sector. If this is indeed the case and the scarcity of electrical engineers is still an important factor after 2030, this will have to be taken into consideration during the decision-making process. More specific research is needed to ascertain the labour resources required to install ERS or charging facilities and the expected scarcity of these occupations after 2030 in order to assess this aspect properly.

5.10 Detours: the impact could be significant if there is a limited ERS network

The use of ERS may have an impact on the number of vehicle-kilometres travelled. For example, it is conceivable (especially in the case of a limited ERS network) that scheduling routes for HGVs will focus on charging so that the ERS network can be used for a longer time. Or that, on the contrary, longer distances will be travelled to connect to the ERS network. These effects may be significant in terms of social impact. A simple calculation shows that this could run into amounts in the order of tens of millions to several billions of euros.[50] It is unclear whether ERS will result in additional vehicle-kilometres of ERS and, if so, how many. The more extensive the network, the less need there will be for detours.

Also, the different weights of the different types of HGVs we compared in this analysis (O-BEV/BEV) may have an effect on the number of kilometres travelled. Where the weight of the batteries means that an HGV can carry less freight, this means additional journeys are needed. Or, conversely, where lighter battery packs are required for O-BEVs than for the alternatives (BEVs), this means that fewer journeys can be made and therefore fewer kilometres travelled. However, we do not expect this to be the case. In a recent analysis of the impact of batteries on the charging capacity, Hoekstra and EV Consult concluded that as long as they are driving in the Netherlands, transport operators would be able to transport a battery weight of 2 tonnes without any problems (provided the tractor unit is optimised and fitted with 2 rear axles). KiM's previous research[51] also concluded that the weight of goods is increasingly not the limiting factor, mainly due to shifts in the type of goods transported and increases in the charging capacity.

[50] In our calculation we have assumed that ERS will result in 1% additional vehicle-kilometres (as a percentage of the kilometres travelled on ERS). For these additional vehicle-kilometres, we determined what the travel costs would be and what the value of the related travel time would be (expressed in euros using valuation ratios). For alternative 1, the total effect is about EUR 40 million (net present value for the period 2030-2065). For alternatives 2 and 3, we arrived at approximately EUR 2.3 billion and EUR 4.4 billion, respectively.

[51] Francke, J., 2013, Verkenning beladingsgraad goederenvervoer van 45 naar 65%

5.11 Scarcity of mineral resources not a decisive factor

Minerals are needed for batteries, but also for ERS systems and wiring. The finite nature of the mineral resources required for any of the technologies to enable sustainable road transport may be an important factor. The International Energy Agency (IEA), has conducted research[52] on the role that scarce mineral resources can play in the energy transition. According to this study, there are roughly enough mineral resources available worldwide to meet demand (looking ahead to 2040), but the IEA did assume there would be an increase in new mines and recycling. However, a comment was made about the varying quality of mineral resources and therefore the uncertain supply. The IEA also stated that recycling is of great importance and that important steps are also being taken in this regard. If we zoom in more specifically to relevant minerals for ERS and batteries, they are lithium and nickel (for batteries) and copper and aluminium (electricity network). There is sufficient structural evidence of this. But this does not mean that mineral scarcity is not an important concern. However, temporary shortages may occur due to supply problems, geopolitical relations or peaks in demand. This scarcity can have a significant impact on the cost of both technologies. Already, the cost of minerals (including lithium and nickel) makes up 50-70% of the cost of batteries, and the cost of minerals (including copper and aluminium) makes up 20% of the total cost of electricity networks. According to the IEA, a doubling of lithium or nickel prices would lead to a 6% increase in the cost of batteries.

The conclusion is that for both ERS and a battery electric scenario, sufficient mineral resources are available for the time being. However, geopolitical and other developments make this a major concern. This does not seem to be a decisive aspect in accounting for the difference in social cost-effectiveness.

5.12 Conclusion

The start-up losses due to the ERS system not being fully utilised right away are estimated at 4% (WLO High) and 3% (WLO Low) of all costs (both OPEX and CAPEX) during the assumed 35-year lifetime of the network. If these start-up losses have to be recovered, the TCO for O-BEVs (at least for alternatives 2 and 3) will remain competitive. At least in alternative 2, the advantage is lost if only trucks with a daily distance over 180 km use ERS. In alternative 3, the advantage is lost if only trucks with a daily distance over 150 km want to use ERS.

Another important conclusion from this section is that the carbon savings from ERS could be significant, about one third of the annual emissions from road freight transport can be prevented with ERS. The social benefits of this add up to three-quarters of the capital expenditures.

Other potentially important social effects, about which little can be said at the moment, are the effect on road safety, labour shortages (displacement), costs in the deeper electricity network, the environmental impact of copper abrasion and deterioration of the landscape.

[52] IEA, 2021. The Role of Critical Minerals in Clean Energy Transitions.

The inconvenience caused by the ERS construction work is limited. This is not a decisive factor if the work can be carried out at night with only one lane needing to be closed, especially if it can be combined with regular maintenance of the right-hand lane.

Other effects found to be of less importance are the scarcity of mineral resources and other emissions.

Table 5.9. Summary table of social impacts of ERS

Subject	Social impact
Start-up losses during assimilation of network	**Negative:** TCO of O-BEV loses competitive advantage over BEV
Nuisance due to ERS infrastructure construction	**Limited:** social costs marginal compared to other infrastructure costs
Capital expenditures on deep electricity network	**Unclear:** possible positive and negative effects compared with BEV, but more research is needed
Reduction of carbon emissions	**Positive:** ERS could reduce carbon emissions from road freight transport by 33 percent
Safety	**Limited:** Risk of wire break can be resolved by an arrest system. Alternative landing site for trauma helicopters is required.
Visibility of ERS infrastructure on landscape	**Unclear:** impact varies by landscape type. Adverse impacts are to be expected, but the extent of these differs between locations.
Labour market	**Negative/unclear:** In sectors affected by ERS construction, the labour market is expected to remain very tight in 2030. Construction of ERS may therefore cannibalise other activities required for energy transition (as well as the installation of charging points for BEVs, further research required).
Detour	**Negative:** Detours by transport operators to use ERS are only to be expected in limited networks. Depending on how big the detour is, this could have a major impact.
Scarcity of mineral resources	**Limited:** Sufficient mineral resources available for the time being

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6. Sensitivity analyses

As indicated several times in this report, we had to make many assumptions in our analyses. A number of sensitivity analyses were therefore conducted to show the impact of other assumptions. For the sake of clarity, we show the results of the sensitivity analyses for one network alternative, i.e. network alternative 2 and only for WLO Low. Furthermore, the assumption in these calculations is that the start-up losses should be recovered during the rest of the ERS network's lifetime. This is to limit the number of tables. The table below again shows what the basic TCO calculations are.

WLO L with assimilation effect: Medium-distance transport operator		TCO O-BEV 75	TCO O-BEV 100	TCO BEV 200
Alternative 2	Daily distance > 180 km	€ 620,000	€ 630,000	€ 630,000
	Daily distance > 150 km	€ 600,000	€ 610,000	
	Daily distance > 120 km	€ 590,000	€ 600,000	
	Daily distance > 90 km	€ 580,000	€ 590,000	
WLO L with assimilation effect: Long-distance transport operator		**O-BEV 150**	**BEV 400**	**BEV 800**
Alternative 2	Daily distance > 180 km	€ 860,000	€ 890,000	€ 1,000,000
	Daily distance > 150 km	€ 830,000		
	Daily distance > 120 km	€ 810,000		
	Daily distance > 90 km	€ 780,000		

6.1 Sensitivity; ERS demand -30% and -50%

The estimated demand for ERS (the number of HGVs using ERS) is very uncertain, considering for example the important aspects for transport operators besides TCO, as mentioned in 3.2. In this sensitivity analysis, we assume a 30% and a 50% lower demand than estimated in the base calculation (in the case of WLO Low). A 30% lower demand leads to an unfavourable TCO for the O-BEV 75 and O-BEV 100 compared to the BEV 200 if only HGVs with a daily distance greater than 150 km use ERS. The O-BEV 150 loses its advantage (with the BEV 400 only) if only HGVs with daily distances above 180 use ERS.

ERS DEMAND 30%		TCO O-BEV 75	TCO O-BEV 100	TCO BEV 200
Alternative 2	Daily distance > 180 km	€ 660,000	€ 670,000	€ 630,000
	Daily distance > 150 km	€ 640,000	€ 640,000	
	Daily distance > 120 km	€ 620,000	€ 620,000	
	Daily distance > 90 km	€ 600,000	€ 610,000	
ERS DEMAND 30%		**O-BEV 150**	**BEV 400**	**BEV 800**
Alternative 2	Daily distance > 180 km	€ 920,000	€ 890,000	€ 1,000,000

	Daily distance > 150 km	€	880,000
	Daily distance > 120 km	€	850,000
	Daily distance > 90 km	€	820,000

ERS DEMAND 50%		TCO		
		O-BEV 75	O-BEV 100	BEV 200
Alternative 2	Daily distance > 180 km	€ 790,000	€ 800,000	€ 630,000
	Daily distance > 150 km	€ 740,000	€ 750,000	
	Daily distance > 120 km	€ 700,000	€ 710,000	
	Daily distance > 90 km	€ 670,000	€ 680,000	

ERS DEMAND 50%		TCO		
		O-BEV 150	BEV 400	BEV 800
Alternative 2	Daily distance > 180 km	€ 1,150,000	€ 890,000	€ 1,000,000
	Daily distance > 150 km	€ 1,060,000		
	Daily distance > 120 km	€ 1,000,000		
	Daily distance > 90 km	€ 940,000		

A 50% decrease in demand always leads to a less favourable TCO for O-BEV 75 and O-BEV 100 than that of the BEV 200. And the same applies to the O-BEV 150.
In conclusion, a 50% reduction in demand will price an ERS system out of the market. With a 30% drop in demand, the basis is already shaky.

6.2 Construction period three years longer

In this analysis, the construction period of alternative 2 was extended by three years. Instead of taking 5 years to build, it now takes 8 years. As a result, ERS will not be used for an additional three years. This leads to the following TCO calculations:

Construction period + 3 years		TCO		
		O-BEV 75	O-BEV 100	BEV 200
Alternative 2	Daily distance > 180 km	€ 650,000	€ 660,000	€ 630,000
	Daily distance > 150 km	€ 630,000	€ 640,000	
	Daily distance > 120 km	€ 610,000	€ 620,000	
	Daily distance > 90 km	€ 600,000	€ 600,000	

Construction period + 3 years		TCO		
		O-BEV 150	BEV 400	BEV 800
Alternative 2	Daily distance > 180 km	€ 910,000	€ 890,000	€ 1,000,000
	Daily distance > 150 km	€ 870,000		
	Daily distance > 120 km	€ 840,000		
	Daily distance > 90 km	€ 810,000		

In particular, the TCO of the medium-haul O-BEVs loses its advantage if HGVs with daily distances of 150 kilometres and more use ERS.

6.3 BEVs are only charged at night (not on the road)

The TCO calculations of the BEVs now assume that the BEVs are sometimes charged at night and sometimes on the road. The latter is especially necessary for long-haul transport. Of course, on-road charging is more expensive. In the base calculation, 8.3 euro cents per KW/h was used for the charging infrastructure costs. When charging at the operator's own depot, these costs will be lower, i.e. between 2.3 and 4 cents per KW/h. If we assume average infrastructure costs of 4 cents per KW/h for BEVs, we arrive at the following comparison:

Price of static charging down to 4 euro cents		**TCO**		
		O-BEV 75	**O-BEV 100**	**BEV 200**
Alternative 2	Daily distance > 180 km	€ 620,000	€ 630,000	€ 570,000
	Daily distance > 150 km	€ 600,000	€ 610,000	
	Daily distance > 120 km	€ 590,000	€ 600,000	
	Daily distance > 90 km	€ 580,000	€ 590,000	
Price of static charging down to 4 euro cents		**TCO**		
		O-BEV 150	**BEV 400**	**BEV 800**
Alternative 2	Daily distance > 180 km	€ 860,000	€ 800,000	€ 920,000
	Daily distance > 150 km	€ 830,000		
	Daily distance > 120 km	€ 810,000		
	Daily distance > 90 km	€ 780,000		

This turns out to be a very sensitive issue. If BEVs do not need to be recharged on the road, a battery electric alternative is almost always more favourable than an O-BEV. This underlines the importance of monitoring developments such as the recently announced launch of the Tesla Semi, which is said to be capable of travelling 700 kilometres without recharging.

About the calculation of the €0.083 per kWh:

- In the base calculation we have taken the €0.163 per kWh from the Movares report. We have then deducted the 0.08 per kWh for the purchase price of electricity.
- The €0.08 per kWh purchase price consists of 0.05 wholesale price (average according to PBL (2021)) and 0.03 ODE tax for large-scale consumers.)

To validate the €0.083 per kWh, we used the following figures:

- The charging price consists of a mix of depot and on-road charging. We have used a distribution of 85% at depot and 15% in motion. This is based on expert judgement and literature[53].
- For depot charging, we have divided the annual cost of installing and connecting a charger at the depot by the required number of kWh per year. As the installation costs may vary, we have used a low and high scenario and averaged it out. This is based on the earlier study by EV Consult for the Port of Rotterdam Authority.
- For on-road charging (rapid chargers) we have taken a price range of €0.30 - 0.50 per kWh. This range is based on key figures from the market

[53] Topsector Logistiek - Laadinfrastructuur voor elektrische voertuigen in stadslogistiek and CE Delft - Laden voor logistiek in Tilburg

The result was that the average charging price of a BEV would be between €0.0795 and 0.0935. This allowed us to validate Movares' €0.083 and we used it.

6.4 Higher discount rate: from 1.6% to 4.1%

In the reference TCO, a discount rate of 1.6% was used. In this analysis, the discount rate is increased by 2.5% to 4.1%. This analysis is an attractive way of ascertaining whether ERS could be externally funded. So we assumed an interest rate of 2.5%.

Discount rate to 4.1%		TCO		
		O-BEV 75	O-BEV 100	BEV 200
Alternative 2	Daily distance > 180 km	€ 660,000	€ 670,000	€ 630,000
	Daily distance > 150 km	€ 640,000	€ 640,000	
	Daily distance > 120 km	€ 620,000	€ 620,000	
	Daily distance > 90 km	€ 600,000	€ 610,000	
Discount rate to 4.1%		**TCO**		
		O-BEV 150	**BEV 400**	**BEV 800**
Alternative 2	Daily distance > 180 km	€ 930,000	€ 890,000	€ 1,000,000
	Daily distance > 150 km	€ 880,000		
	Daily distance > 120 km	€ 850,000		
	Daily distance > 90 km	€ 820,000		

In particular, the TCO of the medium-haul O-BEVs loses its advantage if HGVs with daily distances of 150 kilometres and more use ERS.

6.5 Capital expenditures 50% higher or 50% lower

This analysis examines what a 50% increase and decrease in capital expenditures means for the TCO.

CAPEX + 50%		TCO		
		O-BEV 75	O-BEV 100	BEV 200
Alternative 2	Daily distance > 180 km	€ 660,000	€ 670,000	€ 630,000
	Daily distance > 150 km	€ 640,000	€ 640,000	
	Daily distance > 120 km	€ 620,000	€ 620,000	
	Daily distance > 90 km	€ 600,000	€ 610,000	
CAPEX + 50%		**TCO**		
		O-BEV 150	**BEV 400**	**BEV 800**
Alternative 2	Daily distance > 180 km	€ 920,000	€ 890,000	€ 1,000,000
	Daily distance > 150 km	€ 880,000		
	Daily distance > 120 km	€ 850,000		
	Daily distance > 90 km	€ 820,000		

CAPEX - 50%		TCO O-BEV 75	TCO O-BEV 100	TCO BEV 200
Alternative 2	Daily distance > 180 km	€ 580,000	€ 590,000	€ 630,000
	Daily distance > 150 km	€ 570,000	€ 580,000	
	Daily distance > 120 km	€ 570,000	€ 570,000	
	Daily distance > 90 km	€ 560,000	€ 570,000	

CAPEX - 50%		TCO O-BEV 150	TCO BEV 400	TCO BEV 800
Alternative 2	Daily distance > 180 km	€ 790,000	€ 890,000	€ 1,000,000
	Daily distance > 150 km	€ 770,000		
	Daily distance > 120 km	€ 760,000		
	Daily distance > 90 km	€ 750,000		

With an increase of 50%, the TCO of the O-BEV 75 and 100 is only favourable if tractor units with daily distances above 150 km use ERS. In all cases, the O-BEV 150 maintains a competitive TCO compared to the BEV 400 and 800.
With a 50% drop in capital expenditures, the TCO of the O-BEVs naturally becomes even more favourable.

6.6 Battery costs lower or higher

The price trend of batteries is also uncertain. This analysis examines the effect on the TCO when battery costs are 50% higher or 50% lower:

Battery costs + 50%		TCO O-BEV 75	TCO O-BEV 100	TCO BEV 200
Alternative 2	Daily distance > 180 km	€ 640,000	€ 650,000	€ 660,000
	Daily distance > 150 km	€ 620,000	€ 630,000	
	Daily distance > 120 km	€ 600,000	€ 620,000	
	Daily distance > 90 km	€ 590,000	€ 600,000	

Battery costs + 50%		TCO O-BEV 150	TCO BEV 400	TCO BEV 800
Alternative 2	Daily distance > 180 km	€ 880,000	€ 960,000	€ 1,140,000
	Daily distance > 150 km	€ 850,000		
	Daily distance > 120 km	€ 830,000		
	Daily distance > 90 km	€ 810,000		

Battery costs - 50%		TCO O-BEV 75	TCO O-BEV 100	TCO BEV 200
Alternative 2	Daily distance > 180 km	€ 610,000	€ 610,000	€ 590,000
	Daily distance > 150 km	€ 590,000	€ 590,000	
	Daily distance > 120 km	€ 580,000	€ 580,000	
	Daily distance > 90 km	€ 570,000	€ 570,000	

	Battery costs - 50%	O-BEV 150	TCO BEV 400	BEV 800
Alternative 2	Daily distance > 180 km	€ 830,000	€ 820,000	€ 870,000
	Daily distance > 150 km	€ 800,000		
	Daily distance > 120 km	€ 780,000		
	Daily distance > 90 km	€ 760,000		

When costs are 50% higher, the TCO of the O-BEVs becomes even more competitive compared to the BEVs. When the battery costs are halved, the TCO of the O-BEV 75 and 100 is only more favourable if HGVs with daily distances above 150 kilometres use ERS. The O-BEV 150 remains more favourable than the BEV 400 and 800.

6.7 Patterns less fixed than expected

Table 4.3 in Section 3 shows the factors used to estimate what proportion of trucks travel a sufficiently regular pattern in the year to be replaced by an O-BEV. For alternative 2, a factor of 0.65 is applied. This analysis examines the impact of lowering that factor by 0.2, to 0.45.

	From 0.65 to 0.45.	O-BEV 75	TCO O-BEV 100	BEV 200
Alternative 2	Daily distance > 180 km	€ 660,000	€ 670,000	€ 630,000
	Daily distance > 150 km	€ 640,000	€ 640,000	
	Daily distance > 120 km	€ 620,000	€ 630,000	
	Daily distance > 90 km	€ 600,000	€ 610,000	
	From 0.65 to 0.45.	**O-BEV 150**	**TCO BEV 400**	**BEV 800**
Alternative 2	Daily distance > 180 km	€ 930,000	€ 890,000	€ 1,000,000
	Daily distance > 150 km	€ 880,000		
	Daily distance > 120 km	€ 850,000		
	Daily distance > 90 km	€ 820,000		

The demand for ERS is reduced as a result, so that in all cases the TCO rises compared to the reference TCO. O-BEV 75 and 100 are competitive with the BEV 200 only if HGVs with daily distances above 120 km use ERS. The O-BEV 150 remains competitive in relation to the BEV 400 and 800.

6.8 Conclusion

The sensitivity analyses show that the TCO of the O-BEVs, especially for the medium distance (the O-BEV 75 and 100 compared to the BEV 200) is sensitive to different assumptions. The main sensitivity lies in the charging costs of BEVs. If they can be charged entirely at the depot (i.e. especially at night), the TCO of BEVs is almost always more favourable than that of O-BEVs. In addition, demand is obviously an important factor. If transport demand were 50% lower, the benefit of ERS would disappear for all transport. But even if demand were 30% lower, the advantage of the O-BEV at medium distance would be reduced. This eliminates HGVs with shorter daily distances (up to 150 kilometres). The same applies if a 2.5% higher discount rate is used, if the construction costs double, if the construction period is extended by 3 years (with the additional start-up losses) and if the patterns travelled by HGVs are significantly less fixed than we have estimated. A halving of battery prices has a somewhat smaller impact. We also see that in the event of windfall events, such as lower costs or a doubling of battery prices (which would work out in favour of ERS), the TCO naturally becomes even more favourable compared to the BEVs.

Summary of sensitivity analyses

Sensitivity analysis	Effect
ERS usage 50% lower than estimated	TCO of O-BEV becomes more unfavourable than BEV
On-road charging is no longer necessary for BEVs	TCO of O-BEV becomes more unfavourable than BEV
ERS usage 30% lower than estimated	TCO of O-BEV only more favourable if trucks with daily distances over 120 kilometres use ERS
Construction period three years longer	TCO of O-BEV only more favourable if trucks with daily distances over 120 kilometres use ERS
Discount rate 4.1%	TCO of O-BEV only more favourable if trucks with daily distances over 120 kilometres use ERS
50% increase in capital expenditures	TCO of O-BEV only more favourable if trucks with daily distances over 120 kilometres use ERS
Less fixed annual patterns for HGVs	TCO of O-BEV only more favourable if trucks with daily distances over 120 kilometres use ERS
Battery costs 50% lower	TCO of O-BEV only more favourable if trucks with daily distances over 150 kilometres use ERS

7. Uncertainties to be monitored or studied

This study was conducted over a short period of time, using existing data and information and building on the research of Movares.
In view of the many uncertainties that remain, we emphasise that the conclusions of the study should be treated with caution. Below, we list the main uncertainties again, indicating whether they are points to be monitored or whether specific research is needed.

To be monitored:

- OEMs: For an ERS network to be successful, an adequate and competitive supply of O-BEVs is required. This is not the case at the moment. The number of manufacturers who are seriously working on this is still limited. This in itself is an important reason why an ERS network should only be built if other countries are also involved.
- The introduction of new electric trucks with a much better price/quality ratio than assumed in the TNO market study. A specific example is the Tesla Semi, which is scheduled to come on to the market this year and is said to be capable of transporting over 36 tonnes over 700 kilometres without recharging. If Tesla makes this happen and can also deliver this vehicle in large numbers, the foundations on which ERS rests may crumble.
- Trends in battery prices, the number of charging cycles and other qualities can have a significant impact on the TCO of BEVs and therefore also on the relationship with the TCO of O-BEVs. Trends develop quickly and the demand for batteries is growing exponentially. It is therefore very important to monitor this situation.
- Alternatives to ERS with overhead line. A test track for induction charging will be constructed this summer in Germany. This is probably a more expensive option, but has the advantage that it does not cause any visual impact and can also be used for vehicles such as delivery vans. Different technologies have also been piloted in Sweden and other countries.
- Hydrogen developments. At present, hydrogen is not yet a competitive option for road transport due to cost and loss of energy efficiency. But it is a fast-moving situation. It is therefore essential to monitor these developments closely and continue to weigh them against any investment in ERS.

Research specific to the Netherlands:

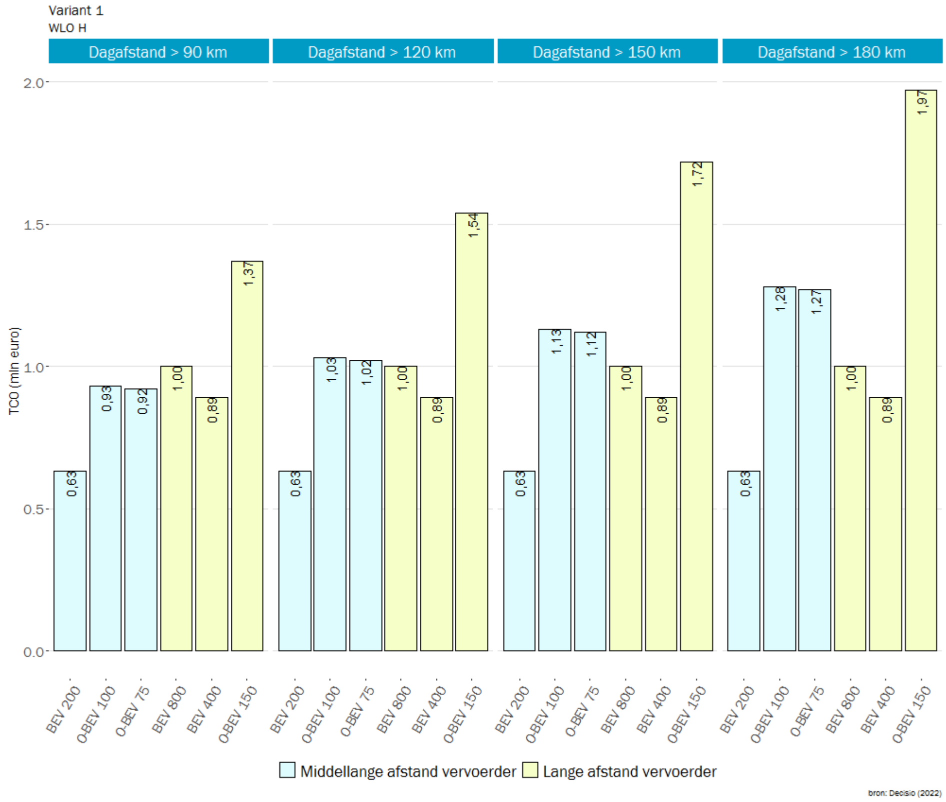
- The investment required in the electricity network. This includes both the specific investment required to create an extensive ERS network and the investment required in the high- and medium-voltage network in the Netherlands in order to be able to supply the ERS network with sufficient peak capacity everywhere. This should be compared to the same investment that would be needed without ERS, when BEVs would have to be charged at charging points and rapid chargers.
- Statistics Netherlands microdata could be used to provide a better picture of the logistics pattern of trucks travelling within (or through) the Netherlands. Expert judgements were used in this study to establish which trucks travel more or less fixed patterns throughout the year.

- Labour shortages and the energy transition. More in-depth research is required to ascertain which occupations are relevant to ERS and electric charging (and to what extent) and what the shortage is expected to be in these occupations from 2030 onwards.
- Research into the scheduling of the preparation and construction of an ERS network. This study assumes that construction will begin in 2030 and take 5 - 7 years to complete. It is important to conduct research to establish whether this is realistic.

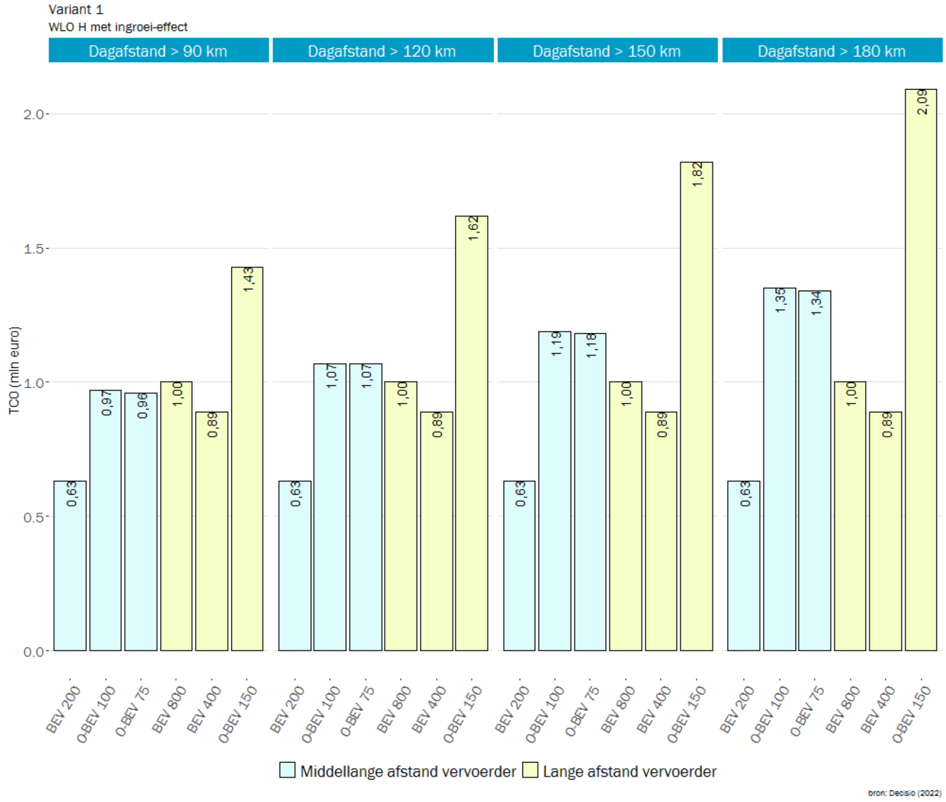
Research points not specific to the Netherlands:

- Safety. The safety of the system, especially what can happen if a cable breaks, is of course an important issue. A solution must be found for this, as creating potentially life-threatening situations on the motorway could be a game changer.
- There is considerable abrasion of copper in the overhead line and, as copper is toxic, this could have a significant impact. The above needs to be clarified in further research. We could not find any international studies on the subject of this impact.
- Controlling the use of ERS. If too many O-BEVs are using the ERS at the same time (close together), there may be insufficient power, either firstly to recharge or, when it gets really busy, to be able to drive on at full speed. This must, of course, be prevented and is another aspect that requires further research.

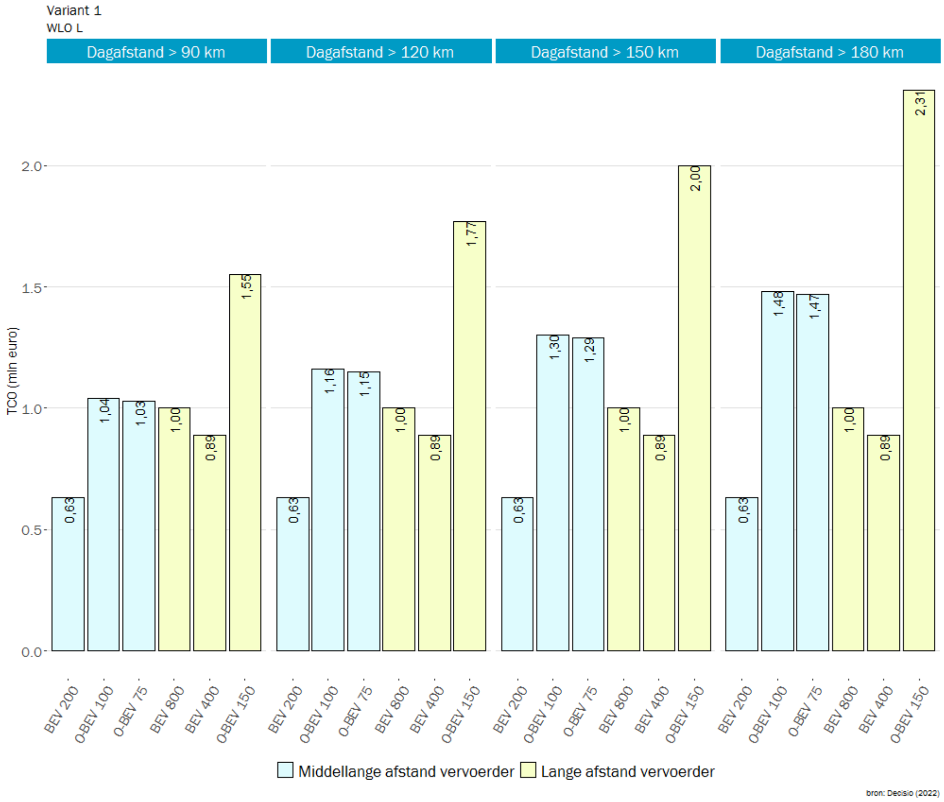
Appendix 1 TCO for WLO L/H with/without assimilation effects

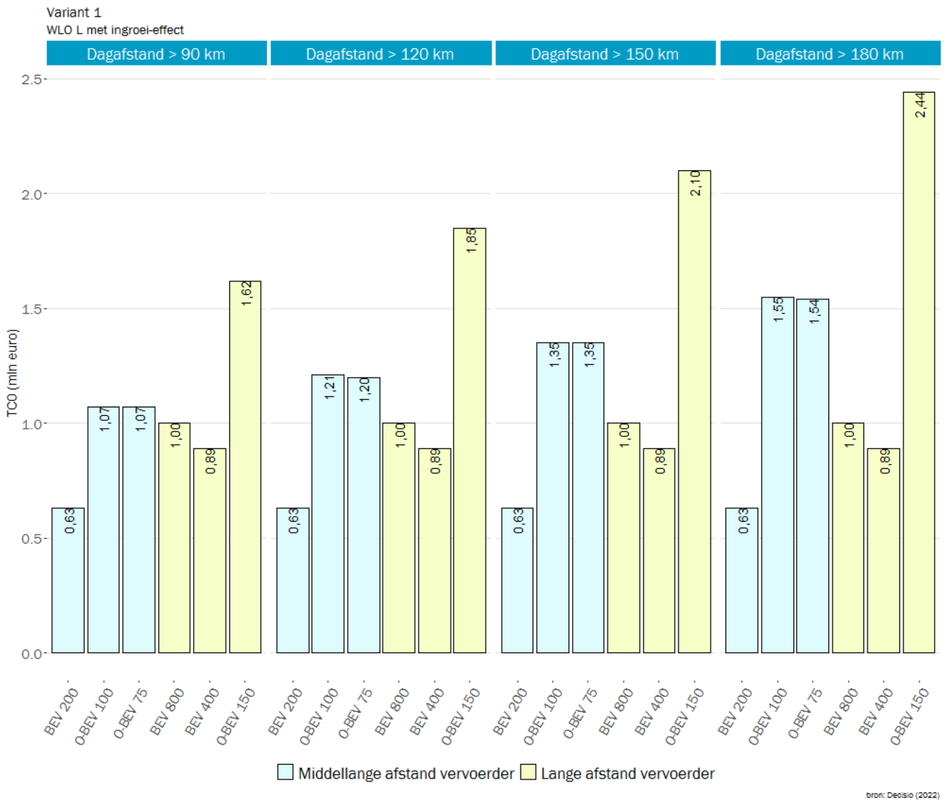


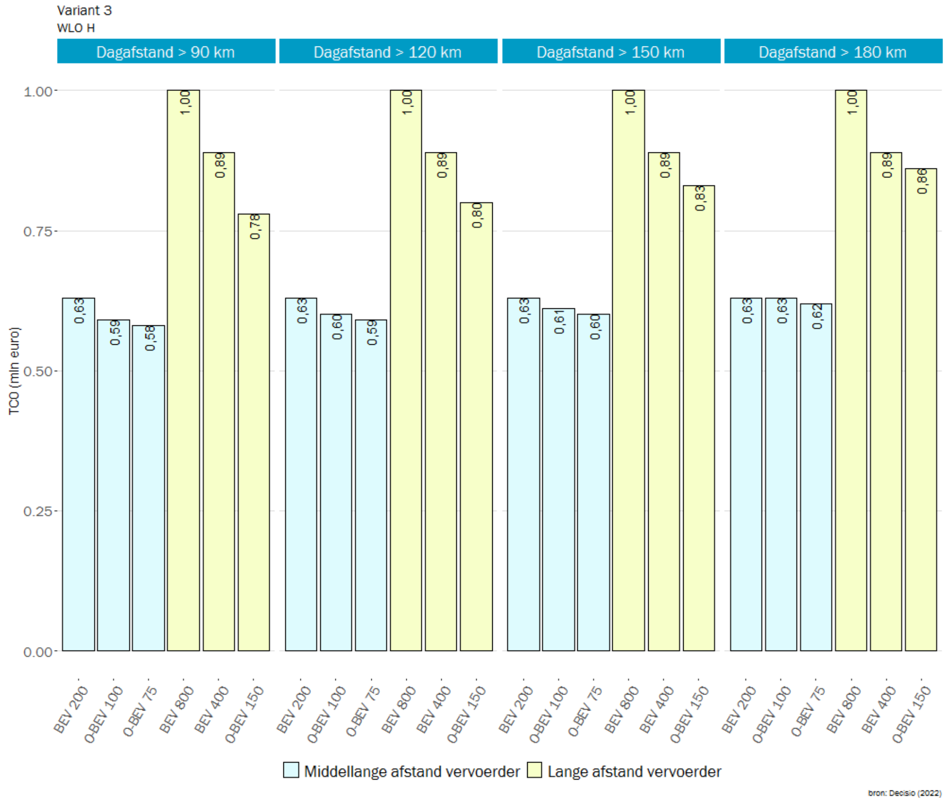
Variant 1
WLO H
Dagafstand > 90 km
Dagafstand > 120 km
Dagafstand > 150 km
Dagafstand > 180 km
TCO (mln euro)
BEV 200
O-BEV 100
O-BEV 75
BEV 800
BEV 400
O-BEV 150
Middellange afstand vervoerder
Lange afstand vervoerder
bron: Decisio (2022)



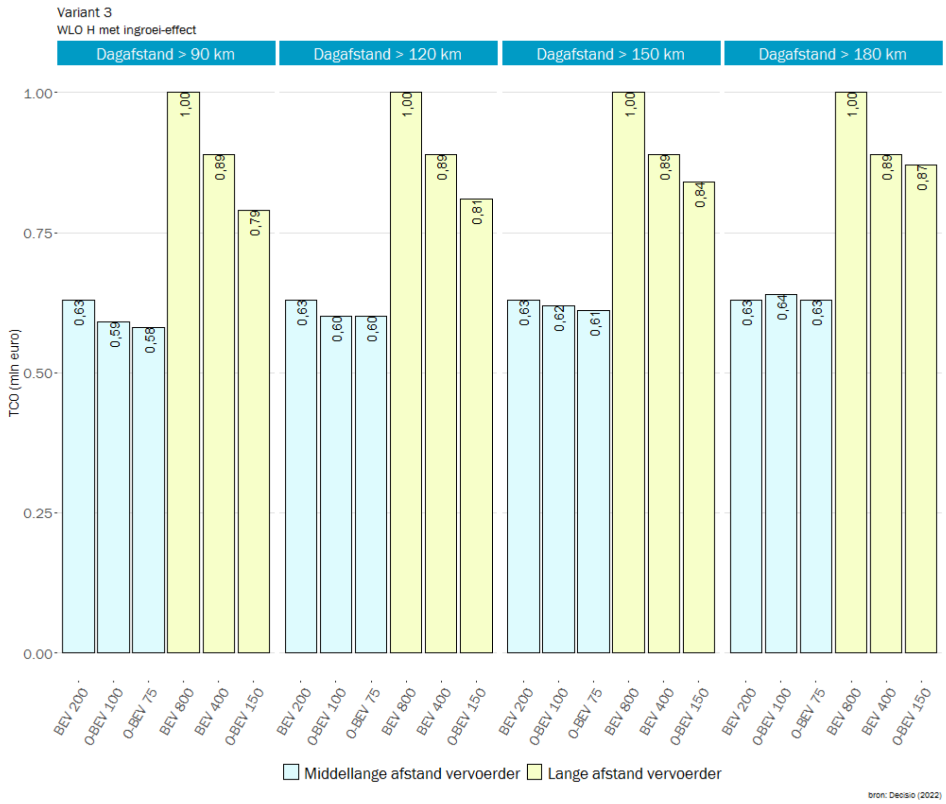
Variant 1
WLO H met ingroei-effect
Dagafstand > 90 km
Dagafstand > 120 km
Dagafstand > 150 km
Dagafstand > 180 km
TCO (mln euro)
BEV 200
O-BEV 100
O-BEV 75
BEV 800
BEV 400
O-BEV 150
Middellange afstand vervoerder
Lange afstand vervoerder
bron: Decisio (2022)


Variant 1
WLO L
Dagafstand > 90 km
Dagafstand > 120 km
Dagafstand > 150 km
Dagafstand > 180 km
TCO (mln euro)
0,63
1,04
1,03
1,00
0,89
1,55
0,63
1,16
1,15
1,00
0,89
1,77
0,63
1,30
1,29
1,00
0,89
2,00
0,63
1,48
1,47
1,00
0,89
2,31
BEV 200
O-BEV 100
O-BEV 75
BEV 800
BEV 400
O-BEV 150
Middellange afstand vervoerder
Lange afstand vervoerder
bron: Decisio (2022)

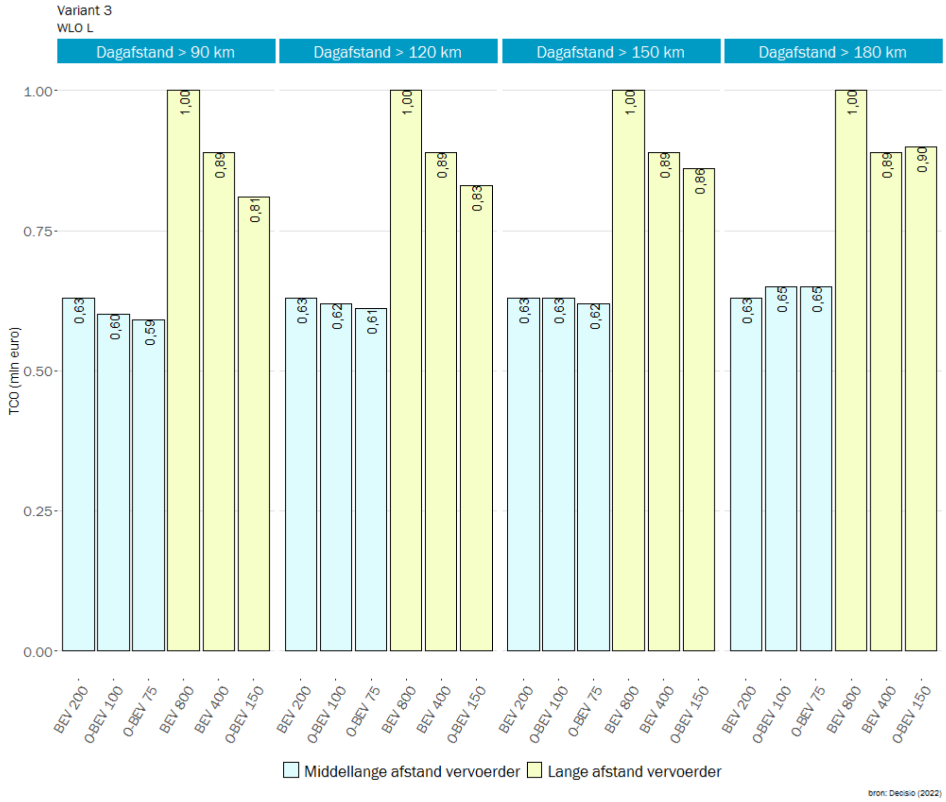

Variant 1
WLO L met ingroei-effect
Dagafstand > 90 km
Dagafstand > 120 km
Dagafstand > 150 km
Dagafstand > 180 km
TCO (mln euro)
0,63
1,07
1,07
1,00
0,89
1,62
0,63
1,21
1,20
1,00
0,89
1,85
0,63
1,35
1,35
1,00
0,89
2,10
0,63
1,55
1,54
1,00
0,89
2,44
BEV 200
O-BEV 100
O-BEV 75
BEV 800
BEV 400
O-BEV 150
Middellange afstand vervoerder
Lange afstand vervoerder
bron: Decisio (2022)

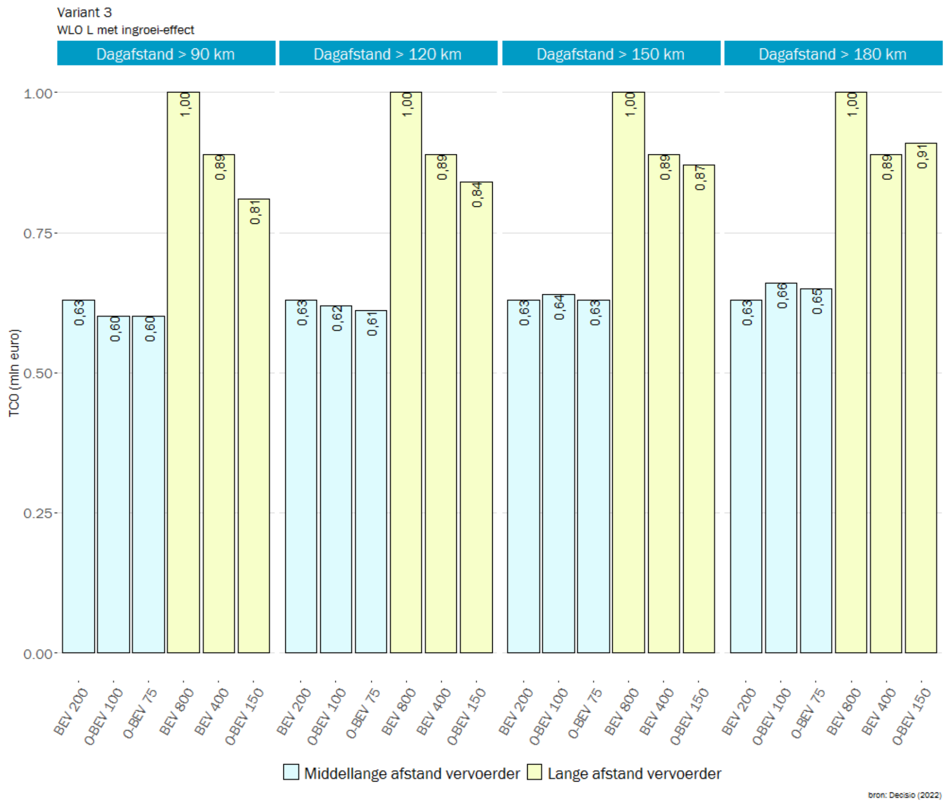


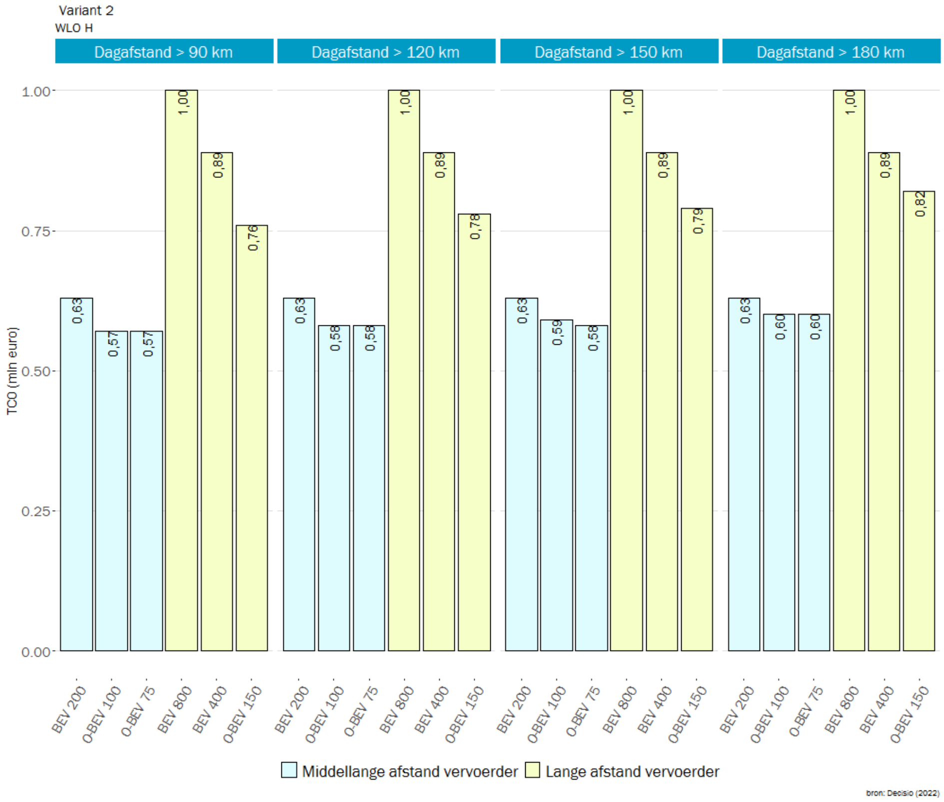
Variant 3
WLO H
Dagafstand > 90 km
Dagafstand > 120 km
Dagafstand > 150 km
Dagafstand > 180 km
TCO (mln euro)
1.00
0.75
0.50
0.25
0.00
0,63
0,59
0,58
1,00
0,89
0,78
0,63
0,60
0,59
1,00
0,89
0,80
0,63
0,61
0,60
1,00
0,89
0,83
0,63
0,63
0,62
1,00
0,89
0,86
BEV 200
O-BEV 100
O-BEV 75
BEV 800
BEV 400
O-BEV 150
Middellange afstand vervoerder
Lange afstand vervoerder
bron: Decisio (2022)

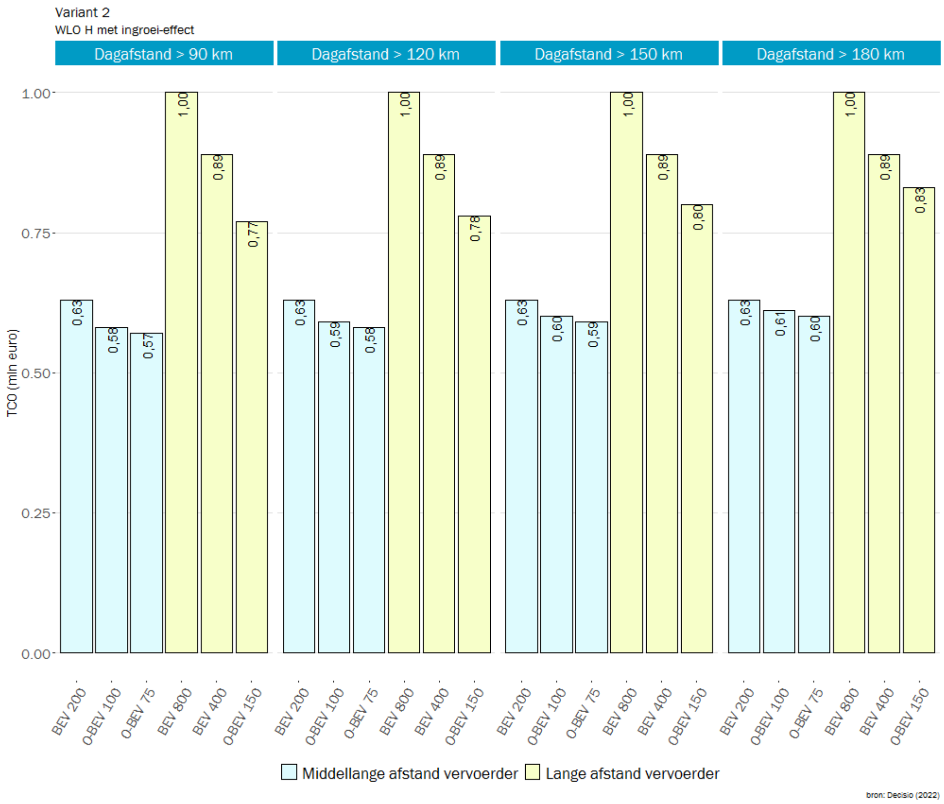


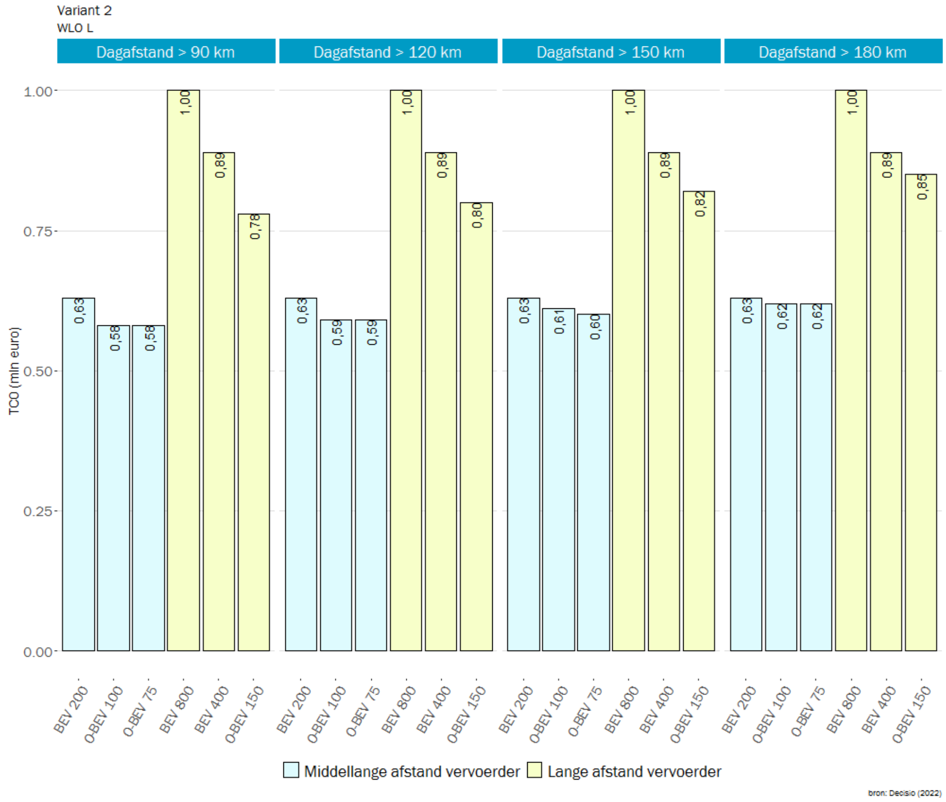
Variant 3
WLO H met ingroei-effect
Dagafstand > 90 km
Dagafstand > 120 km
Dagafstand > 150 km
Dagafstand > 180 km
TCO (mln euro)
1.00
0.75
0.50
0.25
0.00
0,63
0,59
0,58
1,00
0,89
0,79
0,63
0,60
0,60
1,00
0,89
0,81
0,63
0,62
0,61
1,00
0,89
0,84
0,63
0,64
0,63
1,00
0,89
0,87
BEV 200
O-BEV 100
O-BEV 75
BEV 800
BEV 400
O-BEV 150
Middellange afstand vervoerder
Lange afstand vervoerder
bron: Decisio (2022)

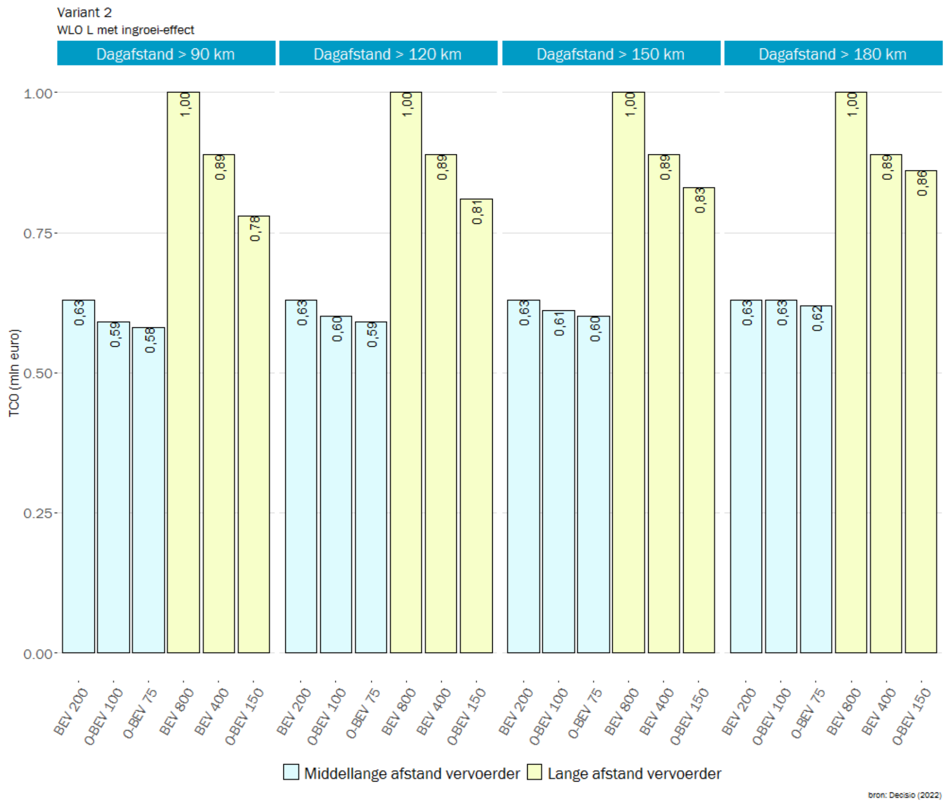

Variant 3
WLO L
Dagafstand > 90 km
Dagafstand > 120 km
Dagafstand > 150 km
Dagafstand > 180 km
TCO (mln euro)
0.00
0.25
0.50
0.75
1.00
0,63 0,60 0,59 1,00 0,89 0,81
0,63 0,62 0,61 1,00 0,89 0,83
0,63 0,63 0,62 1,00 0,89 0,86
0,63 0,65 0,65 1,00 0,89 0,90
BEV 200
O-BEV 100
O-BEV 75
BEV 800
BEV 400
O-BEV 150
Middellange afstand vervoerder
Lange afstand vervoerder
bron: Decisio (2022)


Variant 3
WLO L met ingroei-effect
Dagafstand > 90 km
Dagafstand > 120 km
Dagafstand > 150 km
Dagafstand > 180 km
TCO (mln euro)
0.00
0.25
0.50
0.75
1.00
0,63 0,60 0,60 1,00 0,89 0,81
0,63 0,62 0,61 1,00 0,89 0,84
0,63 0,64 0,63 1,00 0,89 0,87
0,63 0,66 0,65 1,00 0,89 0,91
BEV 200
O-BEV 100
O-BEV 75
BEV 800
BEV 400
O-BEV 150
Middellange afstand vervoerder
Lange afstand vervoerder
bron: Decisio (2022)


Variant 2
WLO H
Dagafstand > 90 km
Dagafstand > 120 km
Dagafstand > 150 km
Dagafstand > 180 km
TCO (mln euro)
0,63 0,57 0,57 1,00 0,89 0,76
0,63 0,58 0,58 1,00 0,89 0,78
0,63 0,59 0,58 1,00 0,89 0,79
0,63 0,60 0,60 1,00 0,89 0,82
BEV 200 O-BEV 100 O-BEV 75 BEV 800 BEV 400 O-BEV 150
Middellange afstand vervoerder
Lange afstand vervoerder
bron: Decisio (2022)


Variant 2
WLO H met ingroei-effect
Dagafstand > 90 km
Dagafstand > 120 km
Dagafstand > 150 km
Dagafstand > 180 km
TCO (mln euro)
0,63 0,58 0,57 1,00 0,89 0,77
0,63 0,59 0,58 1,00 0,89 0,78
0,63 0,60 0,59 1,00 0,89 0,80
0,63 0,61 0,60 1,00 0,89 0,83
BEV 200 O-BEV 100 O-BEV 75 BEV 800 BEV 400 O-BEV 150
Middellange afstand vervoerder
Lange afstand vervoerder
bron: Decisio (2022)


Variant 2
WLO L
Dagafstand > 90 km
Dagafstand > 120 km
Dagafstand > 150 km
Dagafstand > 180 km
TCO (mln euro)
1.00
0.75
0.50
0.25
0.00
0,63
0,58
0,58
1,00
0,89
0,78
0,63
0,59
0,59
1,00
0,89
0,80
0,63
0,61
0,60
1,00
0,89
0,82
0,63
0,62
0,62
1,00
0,89
0,85
BEV 200
O-BEV 100
O-BEV 75
BEV 800
BEV 400
O-BEV 150
Middellange afstand vervoerder
Lange afstand vervoerder
bron: Decisio (2022)


Variant 2
WLO L met ingroei-effect
Dagafstand > 90 km
Dagafstand > 120 km
Dagafstand > 150 km
Dagafstand > 180 km
TCO (mln euro)
1.00
0.75
0.50
0.25
0.00
0,63
0,59
0,58
1,00
0,89
0,78
0,63
0,60
0,59
1,00
0,89
0,81
0,63
0,61
0,60
1,00
0,89
0,83
0,63
0,63
0,62
1,00
0,89
0,86
BEV 200
O-BEV 100
O-BEV 75
BEV 800
BEV 400
O-BEV 150
Middellange afstand vervoerder
Lange afstand vervoerder
bron: Decisio (2022)

Appendix 2 Interviewees

Sacha Scheffer - Dutch Ministry of Infrastructure and Water Management
Jan Francke – Kennisinstituut voor mobiliteitsbeleid (KiM)
Rob Aarse - Transport and Logistics Netherlands
Rutger de Croon - E-laad
Ruud Smit - Rijkswaterstaat
Lisanne Labrujere - Movares
Marco Duijnisveld- Movares
Raimonds Aronietis - University of Antwerp
Markus Auerbach - BAST (German Federal Road Administration)

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Appendix 4 Assumptions for TCO calculation

Medium Haul			Long Haul		
Parameter		**Unit**	**Parameter**		**Unit**
CAPEX on tractor chassis	65.000	€	CAPEX on tractor chassis	65.000	€
CAPEX on conventional power train (Diesel)	54.000	€	CAPEX on conventional power train (Diesel)	54.000	€
CAPEX on conventional power train (O-HEV)	49.000	€	CAPEX on conventional power train (O-HEV)	49.000	€
CAPEX on fuel cell power train	5.000	€	CAPEX on fuel cell power train	5.000	€
CAPEX on fuel cell H2 tank & battery (index	64.250	€	CAPEX on fuel cell H2 tank & battery (indexed)	64.250	€
CAPEX on fuel cell electronics (indexed)	166.000	€	CAPEX on fuel cell electronics (indexed)	166.000	€
CAPEX on BEV battery costs	150	€/kWh	CAPEX on BEV battery costs	150	€/kWh
CAPEX on electric motor	4.900	€	CAPEX on electric motor	4.900	€
CAPEX on hybrid power train	14.000	€	CAPEX on hybrid power train	14.000	€
CAPEX on BEV power train	14.000	€	CAPEX on BEV power train	14.000	€
CAPEX on pantograph	19.000	€	CAPEX on pantograph	19.000	€
CAPEX on O-HEV battery	800	€	CAPEX on O-HEV battery	800	€
Battery size for FCEV	75	kWh	Battery size for FCEV	75	kWh
Battery size for O-BEV 75	135	kWh	Grootte batterij O-BEV 150	270	kWh
Battery size for O-BEV 100	180	kWh	Grootte batterij BEV 400	700	kWh
Battery size for BEV 200	350	kWh	Grootte batterij BEV 800	1.400	kWh
Residual value after service life	10,0%	%	Residual value after service life	10,00%	%
Service life	10	year	Service life	10	year
Number of full battery charge cycles	5.000		Number of full battery charge cycles	5.000	
O&M for Diesel	0,16	€/km	O&M for Diesel	0,16	€/km
O&M for FCEV	0,15	€/km	O&M for FCEV	0,15	€/km
O&M for O-HEV	0,152	€/km	O&M for O-HEV	0,152	€/km
O&M for O-BEV	0,112	€/km	O&M for O-BEV	0,112	€/km
O&M for BEV	0,11	€/km	O&M for BEV	0,11	€/km
Number of kilometres per year	70.000	km/year	Number of kilometres per year	120.000	km/year
Price of diesel in 2030	1,55	€/L	Price of diesel in 2030	1,55	€/L
Wholesale electricity price in 2030	0,05	€/kWh	Wholesale electricity price in 2030	0,05	€/kWh
Tax on electricity price in 2030	0,03	€/kWh	Tax on electricity price in 2030	0,03	€/kWh
Electricity price for large-scale consumers	0,08	€/kWh	Electricity price for large-scale consumers	0,08	€/kWh
Price of static charging infrastructure	0,083	€/kWh	Price of static charging infrastructure	0,083	€/kWh
Electricity selling price for static charging	0,163	€/kWh	Electricity selling price for static charging	0,163	€/kWh
Price infrastructure for ERS, CAPEX in both	0,133	€/kWh	Price infrastructure for ERS, CAPEX in both directions	0,133	€/kWh
Electricity selling price for ERS	0,213	€/kWh	Electricity selling price for ERS	0,213	€/kWh
Price of hydrogen (on-site electrolysis)	5,4	€/kg	Price of hydrogen (on-site electrolysis)	5,4	€/kg
Energy costs for diesel	0,158	€/kWh	Energy costs for diesel	0,158	€/kWh
Energy costs for hydrogen	0,162	€/kWh	Energy costs for hydrogen	0,162	€/kWh
Efficiency of diesel	2,38	kWh/km	Efficiency of diesel	2,38	kWh/km
Efficiency of FCEV	2,09	kWh/km	Efficiency of FCEV	2,09	kWh/km
Efficiency of O-HEV	1,86	kWh/km	Efficiency of O-HEV	1,86	kWh/km
Efficiency O-BEV	1,51	kWh/km	Efficiency O-BEV	1,51	kWh/km
Efficiency BEV	1,42	kWh/km	Efficiency BEV	1,42	kWh/km

Parameter: carbon emissions		
Kilometres of freight traffic in the Netherlands in 2030, WLO High	8,1	billion
Kilometres of freight traffic in the Netherlands in 2030, WLO Low	7,5	billion
Carbon emissions for diesel, WLO High	645	gram/kilometre
Carbon emissions for diesel, WLO Low	664	gram/kilometre