MAGPIE

SMART GREEN PORTS

Demonstration report on electric driving with heavy transport trucks

D6.2 - Work Package 6 Demonstration 9

contact@magpie.eu +33 2 35 42 76 12 www.magpie-ports.eu

Funded by the European Union

This project has received funding from the European Union's Horizon 2020 (MFF 2014-2020) research and innovation programme under Grant Agreement 101036594

DEMONSTRATION REPORT ON ELECTRIC DRIVING WITH HEAVY TRANSPORT TRUCKS D6.2

GRANT AGREEMENT NO.	101036594
START DATE OF PROJECT	1 October 2017
DURATION OF THE PROJECT	60 months
DELIVERABLE NUMBER	D6.2
DELIVERABLE LEADER	TNO
DISSEMINATION LEVEL	PU
STATUS	1.0
SUBMISSION DATE	01-10-2025
AUTHORS	Akshay Bhoraskar Erik Gerritse Alessio Lodge Erik van den Tillaart Jaco van Meijeren TNO jaco.vanmeijeren@tno.nl

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101036594.

Modification Control

VERSION #	DATE	AUTHOR	ORGANISATION
V0.1	01-09-2024	A. Bhoraskar	TNO
V0.2	11-09-2025	TNO team	TNO
V0.3	15-09-2025	TNO team	TNO
V0.4	22-09-2025	M. Gatsonides	NMT
V0.5	24-09-2025	A.J. Polman	POR
V1.0	1-10-2025	A. Bhoraskar	TNO

Release Approval

NAME	ROLE	DATE
J. van Meijeren	WP Leader	01-10-2025
Arne-Jan Polman	Peer reviewer	24-9-2025
Martine Gatsonides	Peer reviewer	18-9-2025
Maarten Flikkema	Scientific Coordinator	1-10-2025
Arne-Jan Polman	Project Coordinator	1-10-2025

History of Changes

SECTION, PAGE NUMBER	CHANGE MADE	DATE
	See modification control	

Table of contents

Executive Summary

MAGPIE is a large collaboration project between several European parties with the intention to increase transport efficiency. This deliverable D6.2 specifically focussed on the demonstration of 10 e-trucks operating in container logistics in the Netherlands. Aside the data-driven analysis, the e-truck and logistics assessment also includes a qualitative analysis of this demonstration with respect to the logistic operations and total cost of ownership (TCO) comparisons for e-trucks against diesel for various funding and tax scenarios.

The important findings in this report are summarized below:

Overall demonstration goal:

- A successful heavy road freight logistic operation is demonstrated with the **MAGPIE fleet of 10 e-trucks** in heavy duty container transport business for a **period of more than 24 months**. The e-truck owners –especially in the container transportation business- are all still in an experimentation phase and with alike mindset. Cost of ownership, ability to recharge, operational planning, and limited range are still challenging. In spite of this, the e-truck owners are searching and implementing solutions (often ad hoc) to enable the successful usage of battery-electric vehicles in their daily operations.

e-Truck logistics performance:

- Each e-truck on average drove with a combination weight of 26.2 tonnes (e-trucks with trailer chassis are around 18tonnes) and an average speed of 34.7 km/h.

- The e-trucks drove, on average, 280 km per day and 150 km between each charge. The majority of the trucks do not utilize the full range of the truck every day, with only a few trucks requiring multiple charging events to recharge the battery, cumulatively depleting the energy of the battery at least once a day, highlighting an extensive and multi-faceted usage.

- Across all trips, the e-trucks consumed around 85% of the total energy demand for driving (motor consumption), with the remaining energy consumption split between low voltage loads (7%) related to for instance lights, instrument cluster, controllers and wipers, and various high voltage loads (7%) related to e.g. cabin heating. Brake energy recuperation contributed to lowering the total energy demand by around 12%.

- Limited range and required charging time pose challenges to the scheduling. Daily operational hours were commonly less than for the diesel truck. This effort also leads to review and observations for more efficient conventional diesel-based logistics planning.

- Charging preferably was done at private sites rather than at public locations. This mainly due to the pricing benefit of electricity in combination with a very limited availability of public chargers for heavy-duty e-trucks. Most companies also had opted for a fast charger on-site and simply started fully charging the truck after return to their depot. Although connected overnight, commonly only several hours were needed to top off the battery at 100% SOC and have full range available upon day-start in the morning.

Environmental performance:

- The MAGPIE fleet of e-trucks **avoided 354 tonnes of CO_{2e}** over a total of more than **0.9 million kilometres** across the regions of the Netherlands, resulting in an operational reduction of **44% in GHG emissions.** Low carbon electricity generation are key to further reductions of CO2e emissions.

- The data from the demonstrations and values adopted from the Dutch Emission Registry showed that there were **1921 kg of NO_x emissions avoided** during the demonstration period of this project by utilizing e-trucks. For particle emissions, e-trucks produce **13% less PM_{10} and 47% less $PM_{2.5}$** when compared to equivalent EuroVI diesel trucks. The emission reduction for both NO_x and PM all comes from the avoided tailpipe emissions.

Total Cost of Ownership:

- In terms of operating and ownership costs, the e-trucks are more expensive to buy, yet cheaper to operate. All together, a higher total cost of ownership compared to diesel trucks currently results. This difference can be minimized, at least in the Netherlands when exploiting all incentives (subsidies, tax reduction). Along with technological advancement in the battery and truck, the purchase costs are expected to come down. In the TCO calculation, it is shown that a 10% decrease in the purchase price of the battery-electric vehicle is enough to make it cost-competitive with diesel trucks. Along with upcoming measures like ETS2 and -for Netherlands- the truck tax 'vrachtwagenheffing', a clear positive business case for e-trucks seems very likely by 2030 if not sooner.

1. Acknowledgements

The success of the MAGPIE Project and the resulting report is to be attributed to the continuous support, help and efforts of all parties involved.

We would like to thank to logistic companies involved for their willingness to move towards sustainable trucking through the lease/purchase of heavy-duty electric trucks and the relentless use made of these throughout the demonstration.

Similarly, we would like to thank all other operators and parties involved.

Looking forward, it is our hope and belief that the learnings from this demonstration may serve as a stepping stone for continued scaling up of heavy-duty electric truck fleets across Europe and the globe.

2. Introduction to WP6 Demo 9 on Heavy-Duty Electric Trucks

2.1 Background of the WP6 Demo 9 project

The MAGPIE consortium [1], consisting of 4 ports (Lighthouse Port Rotterdam in the Netherlands, Fellow Ports DeltaPort in Germany, Sines in Portugal and HAROPA in France), 9 research institutes and universities, 32 private companies and 4 other institutes, forms a unique collaboration addressing the missing link between green energy supply and green energy use in port-related transport. The collaboration also focuses on implementation of digitalisation, automation, and autonomy to increase transport efficiency. This project accelerates the introduction of green energy carriers combined with the realisation of logistic optimisation in ports through automation and autonomous operations. A living lab approach is applied in which technological and non-technological innovations are developed and demonstrated. All results feed into the Master Plan for the future European green port, aiming at full decarbonisation by 2050, by providing solutions that can be implemented immediately to make significant steps in decarbonisation already by 2030.

WP6 focuses on demonstrating the feasibility of solutions for GHG-neutral road transport to and from seaports and along hinterland corridors, to prove the benefits of new technologies regarding efficiency and impact on the environment and to demonstrate the prerequisites for a roll-out of new solutions to fellow ports.

Demo 9 *Green Connected Trucking* specifically evaluates the land-based on-road transport modality based on the following subtopics:

1) Connected Zero Emission Transport – Electric driving for heavy road freight transport
2) Connected transport via a decoupling point – Decoupling long haul and first/last mile transport
3) Automated docking for recharging of electric heavy trucks

This report describes the research and outcomes for the first subtopic. The second subtopic was – contrary to expectations during proposal writing – not applied by the transport companies. The third subtopic is reported in MAGPIE deliverable report D6.3.

2.2 Goals for D6.2 on Connected Electric Heavy Truck Transport

The main goal is to demonstrate the electrification of logistic operations with heavy duty battery-electric trucks (hereafter, "e-trucks"). With this demonstration, vehicles, infrastructure technology, and logistics concepts are tested and evaluated, with recommendations made for improvements. It aims to showcase how these concepts and technologies can be applied in the best possible way to reduce emissions and improve the efficiency and reliability of freight transport by road.

Logistic operations with heavy duty battery-electric trucks were expected to become feasible during the project period. On the one hand, this development can have a significant impact on the reduction of emissions, while on the other hand, the novelty of the development still raises many questions that need to be answered to enable large scale adoption and deployment.

This MAGPIE demonstration focusses on the issues affecting e-trucks for road freight of containers and comprises:

- 10 e-trucks
- normal daily logistics operations
- several transport companies
- a duration of (at least) 12 months of operation.

Among the various research questions of interest are:

- How can the energy management of e-trucks be organized to be able to operate them as efficiently and reliably as possible, given variations of transport assignments?
- Can these e-trucks be fitted into the current logistics operation?
- Does the logistics operation need to be adjusted to successfully use e-trucks?
- What is the energy demand of these e-trucks?
- What charging infrastructure is required and at which preferred locations?
- What (real-time) data is needed for energy management and logistics planning?

The overall questions to be answered relate to how these e-trucks can be operated in the most sustainable (zero emission) and optimal way (efficient and reliable) and what needs to be arranged to make this work (such as energy supply/recharging infrastructure and digital infrastructure for data exchange).

This report aims to provide the outcome, findings, and information on the use of e-trucks for road transportation that were operational during the demonstration. This includes the specifications of the vehicles, the routes they drive, the methodology and the outcomes from the data analysis done on these vehicles. In conclusion, this report also answers questions about how logistics operations are affected by the new e-trucks.

3. Research Methodology

3.1 Work breakdown and planning

In order to manage and execute the research and demonstration activities for the *Green Connected Electric Heavy Truck* demonstration, a work breakdown has been defined. Three sequential phases are defined as presented in Figure 1, showing subtasks and involved partners and participants.

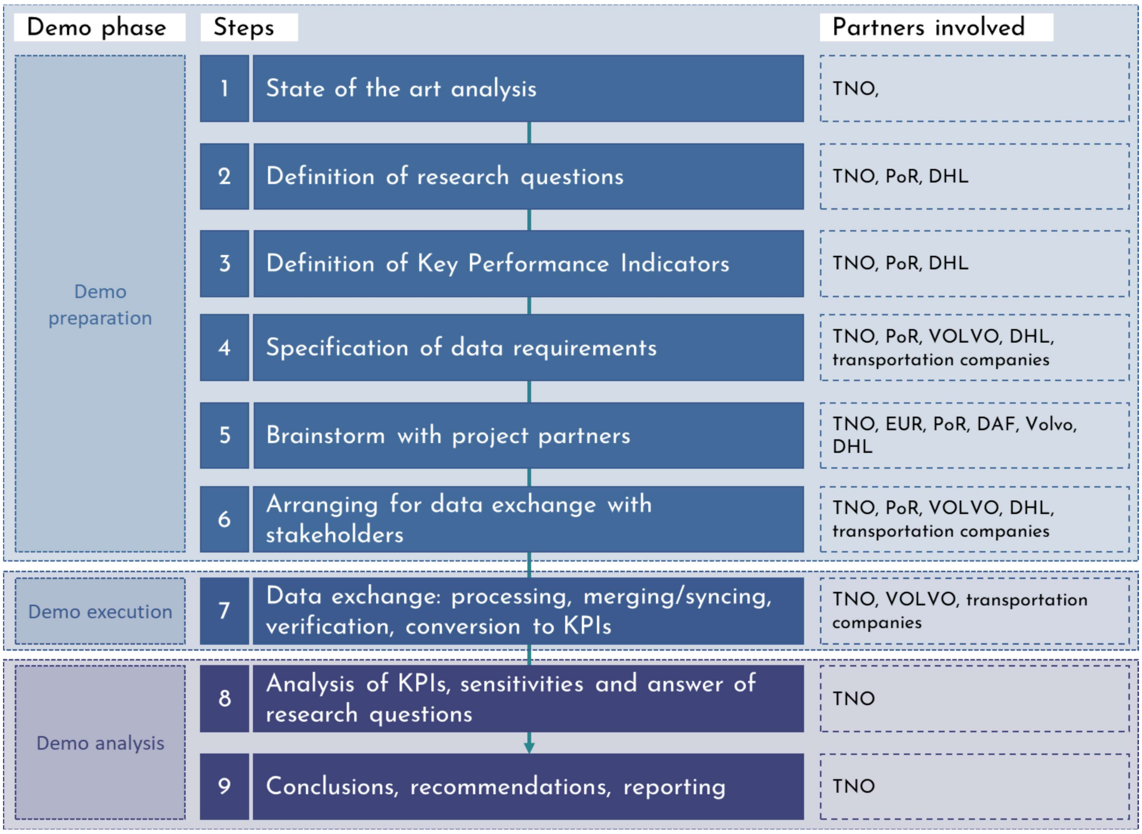

Figure 1: Breakdown of steps for the demonstration

The overall timeline as realized for the *Green Connected Trucking Demonstration* is shown in Table 1. The preparation phase started at M1 of the project and had to be extended compared to the original planning to enable the engagement with transportation companies and to compose a fleet of 10 e-trucks. Altogether, the required monitoring duration of these e-trucks was more than the minimum requirement of 12 months. Some trucks were monitored for twice the operational period starting from April 2023 until the end of Demo 9. This report completes the Electric Truck demonstration with an overview, analysis and future projection at M48 of the project.

Table 1: WP6 Demo9 realization timeline for Electric Heavy Duty Truck demonstration

Demo Phase	2021	2022				2023				2024				2025			
	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	M1			M12				M24				M36				M48	
Preparation																	
Execution							first trucks					All 10 trucks					
Analysis & Report																◊	

◊ marks the deliverable report milestone

3.2 Service area for container logistics

Port of Rotterdam (PoR) in the Netherlands is the lighthouse port for the project, a large seaport for incoming containers on many container terminals. PoR area also connects the different transport modalities like inland waterways, rail and road. Figure 2 shows the PoR area and the road distance towards several hinterland locations. East to West within the PoR area already takes around 40-50km of travel. The roughly 300km single charge range of the e-trucks available is adequate for some cross-border trips. However, to include the return trip, a second full charge is typically necessary. Moreover, distance alone does not cover the challenges of road transportation, as energy consumption and travelling time are highly dependent on driver and traffic conditions.

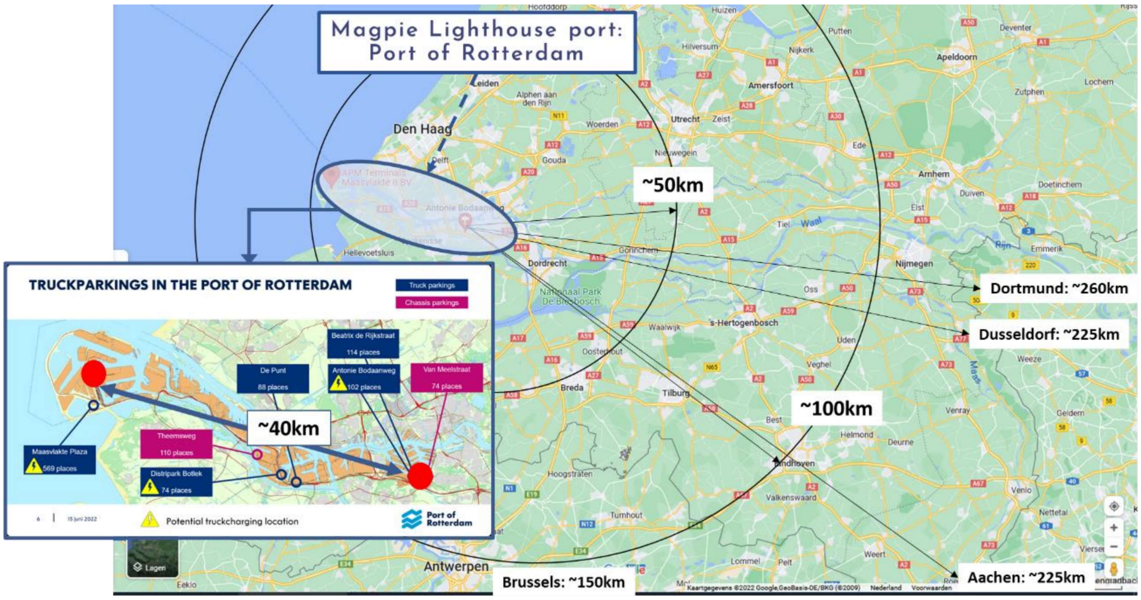

Figure 2: Port of Rotterdam with indicated sky wide radius and road distances to various hinterland locations (source: Google Maps)

When preparing the proposal, the MAGPIE consortium anticipated that by the start of the project, a substantial number of electric heavy-duty trucks would already be in regular operation. However, the actual deployment of the required e-trucks had not yet taken place. Various heavy duty electric trucks had been announced on the market, yet the actual start of delivery following an uptake of investments and orders, were clearly delayed causing a time shift for the start of the demonstration execution phase. The Dutch overall e-truck fleet numbers and annual growth are presented in Figure 3. The e-trucks of interest – tractor units for semi / container chassis operation– are represented in the top two parts in green and grey. A share only emerges after 2022 when Volvo as first OEM started to deliver.

Consequently, a longer search and preparation period with greater effort was needed to engage transportation companies and assemble the desired fleet of 10 e-trucks for the container transportation business in this demonstration.

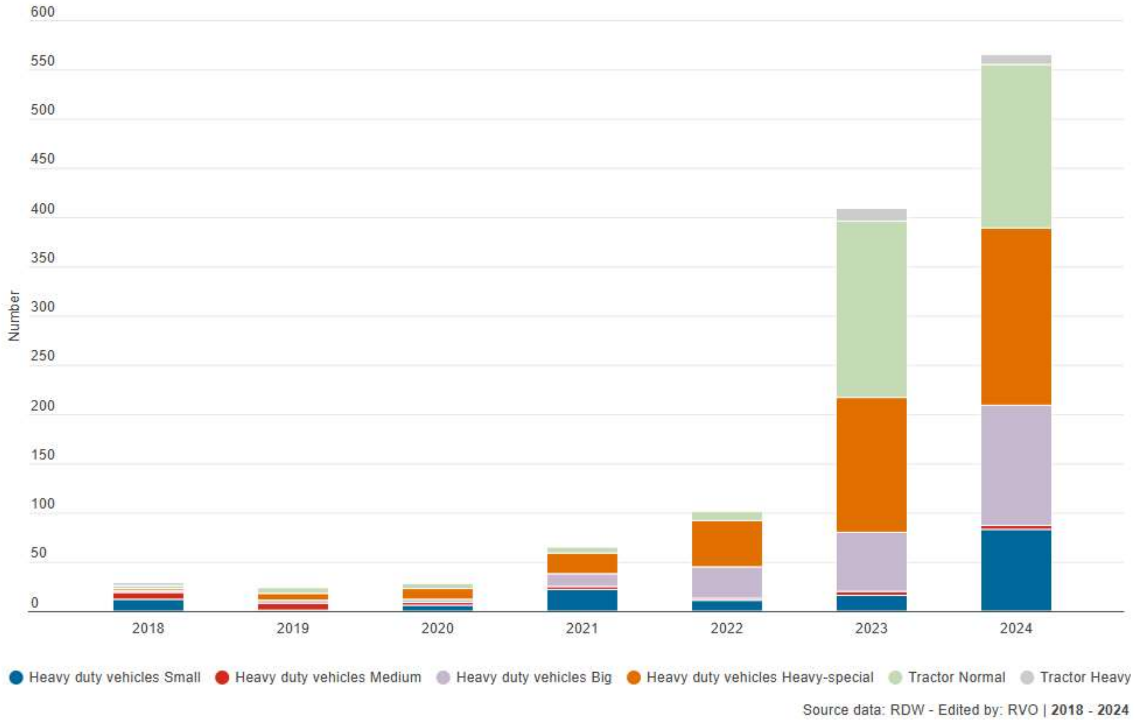

Figure 3: Number of electric trucks in the Dutch fleet (per segment) [2]

3.3 Monitoring approach

In logistic operations, it is common for many transportation companies to apply planning software in combination with fleet management systems. This is a well-established environment for conventional operations planning. The introduction of e-trucks with limited range and longer periods for recharging poses new challenges to the logistics system. An overview of various logistics elements is shown in Figure 4. This includes the harbour area with ships and container terminals, (hinterland) container transshipment/pick-up/drop-off locations, the truck-trailer-container combination and recharging sites. Charging locations may be on-site, close to a container terminal or warehouse, or at (public) charging locations along the roadside.

The truck is the key element in on-road transport, as it visits all relevant locations within container logistics and serves as the primary source of operational data. Information from the e-trucks is uploaded to the cloud and stored on servers from where it can be retrieved, processed, analysed and reported. This allows to calculate various Key Performance Indicators (KPIs) for the e-truck, its operations and its environmental impact during the monitoring period. Data of logistics planning or charger information contains information on (planned) transport (incl. actual payload) or charge event details. Such information can be used to complement the information from the e-truck and provide a more complete set of data.

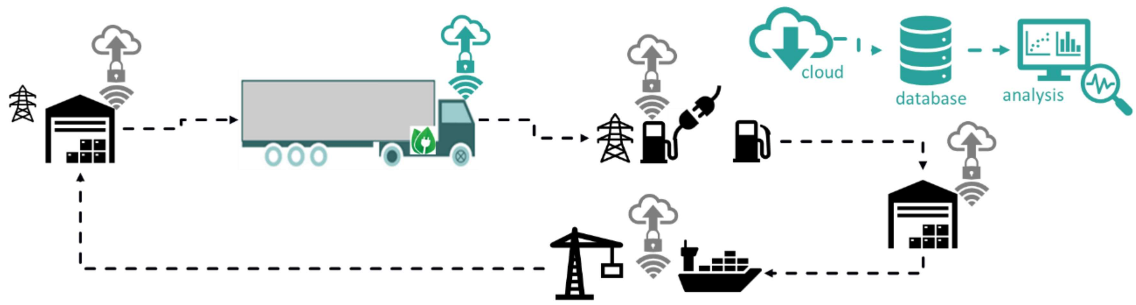

Figure 4: System overview of logistics elements for on-road container transport [3]

During the operational execution of the demonstration in which the trucks operate on day-to-day basis, the data has been periodically analysed and discussed with the transportation companies. This has been repeated throughout the entire period of operation to consistently build and increase understanding of variations in operation. This is visualized in Figure 5.

Figure 5: Iteration loop for execution and analysis phases

3.4 Specification of Key Performance Indicators (KPIs)

An extensive list of KPIs can be defined in the interest of technology assessment and logistics deployment measures. Examples are related to vehicle range and energy consumption, costs of operation, system utilization (e-trucks, charger, driver), driver acceptance and environmental impact. An initial list was drafted by WP8 and already reported in the state-of-art overview for Demo 9 [4]. To define the KPIs, the following steps were taken:

1. Based on the results and lessons learned of section 4.3 (in [4]), a first list of indicators is drafted
2. These indicators are discussed together with other parties within MAGPIE, in particular with parties from WP8
3. The results of the brainstorm are reported in the MAGPIE D8.1 – *Measurement requirements, method and KPIs framework*. In particular, for Demo 9 sub-demo 1, the selected indicators are reported in Table 2.

Table 2: List of KPIs from MAGPIE WP8 [4]

Impact area	KPI	Description
Environmental • Per unit of transport activity • Per transhipment • Per demo per year	CO_{2e}	CO2-equivalent emissions
	Energy use	Energy usage
	Pollutant x	Emissions of a pollutant x (PM2.5, PM10, Methane, SOx, NOx, NH_3)
Operational	Lead time freight	Time that is needed to move a shipment from start to end location within the demo
	Charging time	Time that is needed to charge the vehicle, including the rerouting of the vehicle to look for a charging facility (if applicable)
Socio-economic	Added value	The amount of added value realised directly or indirectly by the demo
	Operational expenditures (OPEX)	The total operational costs of the demo
	Capital expenditures (CAPEX)	The total capital costs of the demo
	Amount of green investment (OPEX/CAPEX)	Green investment costs in the demo
	Social acceptance	Development of a framework for the social acceptance of the demo

The KPIs from Table 2 are to be obtained from the collected and processed monitoring data, which then consists of:

- Trip information
  - Start and end location of trips
  - Start and end times of trips
  - Ambient temperature during trips
- Vehicle specifications
  - Vehicle range
  - Vehicle speed (monitored during trips)
  - GPS location and time (monitored during trips)
- Goods transported
  - Type of goods transported
  - Weight
  - Any relevant specifics (e.g., must be refrigerated)
- Battery specifications
  - Battery capacity
  - Battery voltage
  - Battery power (charge and discharge)
  - State of charge (monitored during trips)

- Charging time [minutes/charging cycle]

- Energy consumption and emissions[1]
    - Consumption during standstill [kWh/hour]
    - Energy consumption [kWh/km]
    - CO_2 emissions at the tank-to-wheel level
        - Primary data (if applicable)
        - Default emission factors
    - Where the origin of energy is known, the well-to-wheel CO_{2e} emissions

- Costs aspects
    - Vehicle purchase price, depreciation and estimated residual value
    - Vehicle retrofit price (if applicable)
    - Costs of charging infrastructure (if applicable)
    - Repair and maintenance costs
    - Costs for grid connection

- Employability and acceptance of technology
    - Failure sensitivity and maintenance requirements
    - Driver acceptance
    - Course of the learning process (KPIs over time)
        - Kilometres driven per day over time
        - Unplanned downtime over time
        - Energy consumption over time

[1] For the comparison with diesel vehicles, previous trip data from transport companies will be used. In case that data cannot be retrieved, established assumptions applied by TNO other projects will be used instead.

4. Demonstration use-cases

As per the project proposal [1], 10 e-trucks were operated in the demonstration. The transportation companies along with the e-trucks that were used in the demonstration are listed in Table 3 and their base locations are shown in Figure 6.

Table 3: Overview of transport companies, e-trucks and monitoring period

Transportation company	Number of vehicles	Start of operations monitoring	Last month of monitoring	Vehicle specification
BTT	1	June 2023	August 2025	Volvo FME 44ton, 540 kWh
CTU	2 → 1*	May 2024	August 2025	Volvo FHE 50 ton, 540 kWh
Den Hartogh	2	June 2023 January 2024	August 2025	Volvo FME 50 ton, 450 kWh Volvo FHE 50 ton, 540 kWh
DFDS	2	December 2023	August 2025	Volvo FHE 50 ton, 540 kWh
Van Berkel Group (VBG)	1 → 2*	April 2023	August 2025	Volvo FHE 50 ton, 540 kWh
VEPCO	2	March 2024 June 2024	August 2025	Volvo FME 50 ton, 540 kWh
Total	10			

* Note: one e-truck transferred from CTU to VBG during project period

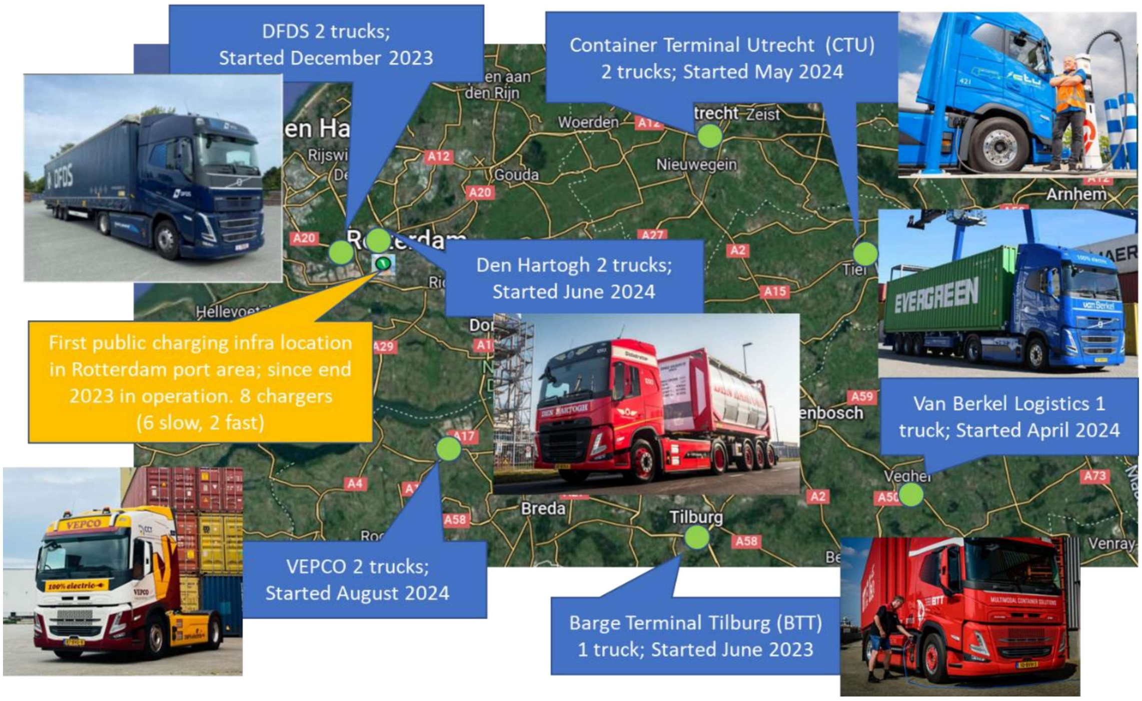

Figure 6: Transportation companies´ primary site locations and their e-trucks

Section 4.1 provides background information on the conditions for individual e-truck usage and the transportation companies. The routes driven by these vehicles vary considerably due to differences in home bases and company specific logistics. The heat maps show an overview with hot spots of frequently visited locations visited by the vehicles, based on the logged GPS tracking data. Since the e-trucks were used for existing logistic operations, they were used on different routes on different days. Section 4.2 provides more details on the Volvo e-truck models as deployed in the MAGPIE demonstration fleet. Unfortunately, no other tractor units have become available during the WP6 Demo 9 research period.

4.1 Participating transportation companies

4.1.1 BTT Multi Modal Container Solutions (BTT)

BTT (Barge Terminal Tilburg) operates various locations, mainly around Tilburg (Netherlands), which serves as the home base for the e-truck operations and the starting point for multimodal container transport by barge or rail.

BTT has mainly deployed a single driver for their operations, and the operations occur mostly during the night. It starts at about 03.00 in the night to about 15.00 in the afternoon. BTT has the following chargers available for use:

- A 90kW charger at their base location that they primarily use
- A 350kW (fast) public charger
- A 43kW charger provided by Volvo as a backup.

The locations visited by the BTT e-truck during its operation are shown in Figure 7.

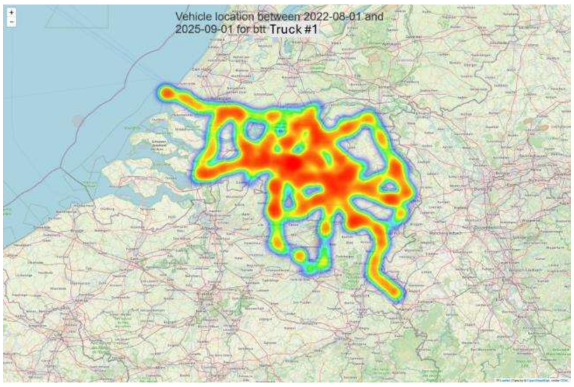

Figure 7: Heatmap of locations of the BTT truck

4.1.2 CTU - Theo Pouw Group

CTU, as part of the Theo Pouw Group, started its operations with 2 e-trucks in their inland terminals in Utrecht and Tiel (both Netherlands) for regional pick-up/drop-off of containers. The e-trucks are driven in two shifts, 7 days a week, with a pool of drivers. They are commonly planned only a day in advance, thereby implying that they are used to a more dynamic planning system. CTU has prepared 16 parallel charger connections in anticipation of a larger e-truck fleet. The expectation is not to have any power limitation for the first e-trucks.

The operations of the two CTU e-trucks throughout the monitoring period can be seen in Figure 8. The inland terminal in Utrecht was transferred to TMA MultiModal during the MAGPIE project whilst continuing the operation of one e-truck. At the same time, the inland terminal Tiel was transferred to the Van Berkel Group, which also continued the operation of the second e-truck. This resulted in a period of less information for the second e-truck due to the transfer. Both e-trucks remained available as part of the MAGPIE demonstration fleet.

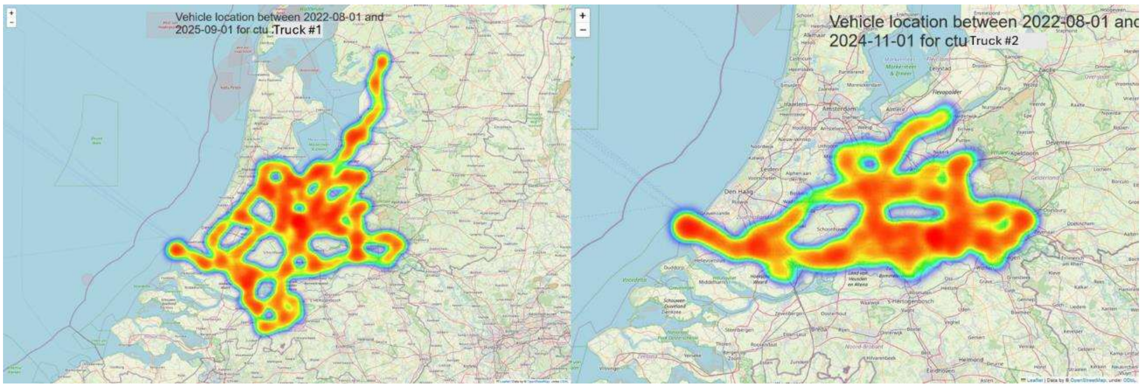

Figure 8: Heatmap of locations for the CTU e-trucks

4.1.3 Den Hartogh Logistics

Den Hartogh is a large Dutch logistics operator that handles chemical, gas, dry bulk and liquid food logistics through multiple transport modalities for global coverage. Their base is in the PoR area, and their fleet consists of over 900 trucks and an even larger number of specialised container chassis.

Den Hartogh has deployed two e-trucks that operate in and from the Rotterdam area. One truck operates locally whereas the second also operates cross-border to the Belgian Antwerp port area and German hinterland. The differences between two trucks is clearly visible in the heatmaps of Figure 9.

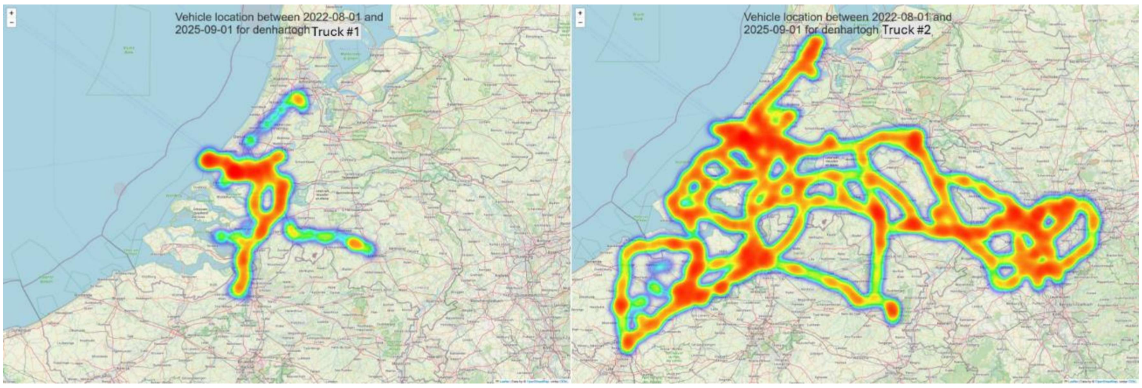

Figure 9: Heatmap for locations of Den Hartogh e-trucks

4.1.4 DFDS

DFDS is a large pan European logistics service provider using all types of transport modalities. DFDS operates a large fleet of trucks and has deployed 145 l heavy duty battery-electric trucks to date at various sites in Europe.

In connection with the MAGPIE project, DFDS has deployed two e-trucks from their Vlaardingen (Netherlands) site for this project. Both trucks operate cross-country and cross-border.

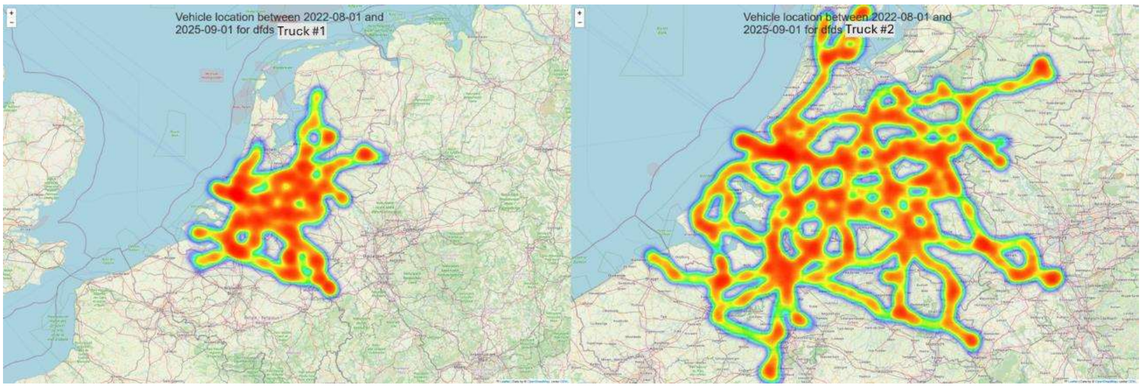

Figure 10: Heatmaps for locations of the DFDS e-trucks

4.1.5 Van Berkel Group (VBG)

The Van Berkel Group provides a large number of services, among which are landscaping, agricultural activities and logistics services for dry bulk storage, transshipment and multi-modal container transportation. Veghel (Netherlands) is the VBG headquarters location where one of the inland terminals is also located. Starting with one e-truck in Veghel, the take-over of inland terminal Tiel (from CTU) also provides continuation of that e-trucks part of the MAGPIE demonstration fleet, despite an interruption of the detailed data services for several months.

In Figure 11 the e-truck locations for the VBG e-trucks are shown to indicate their service area.

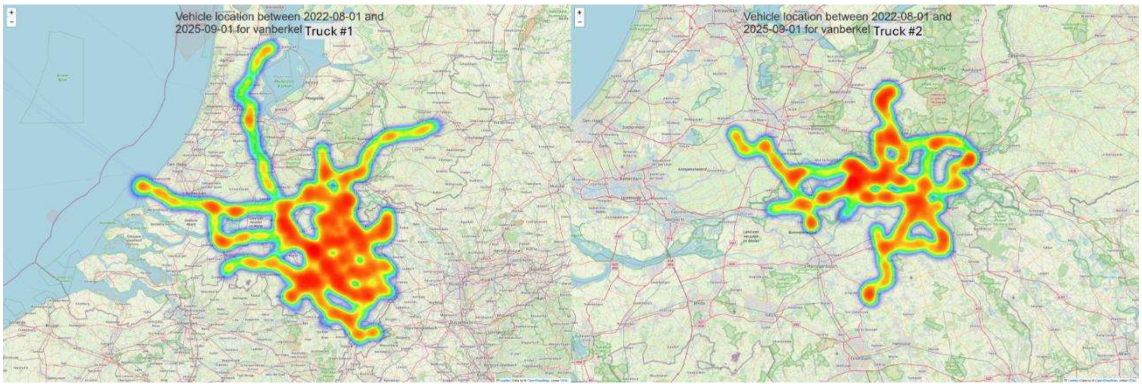

Figure 11: Heatmaps for locations of the VBG e-trucks

4.1.6 VEPCO B.V.

VEPCO is a relatively young full-service logistics provider building a transport hub for container transport just south of the PoR area. From this location, they connect with seaports at Rotterdam and Antwerp (in Belgium), inland terminals and hinterland locations. VEPCO has deployed two e-trucks as part of the MAGPIE demonstration fleet.

Figure 12 shows the locations for the VEPCO-operated e-trucks throughout the monitoring period.

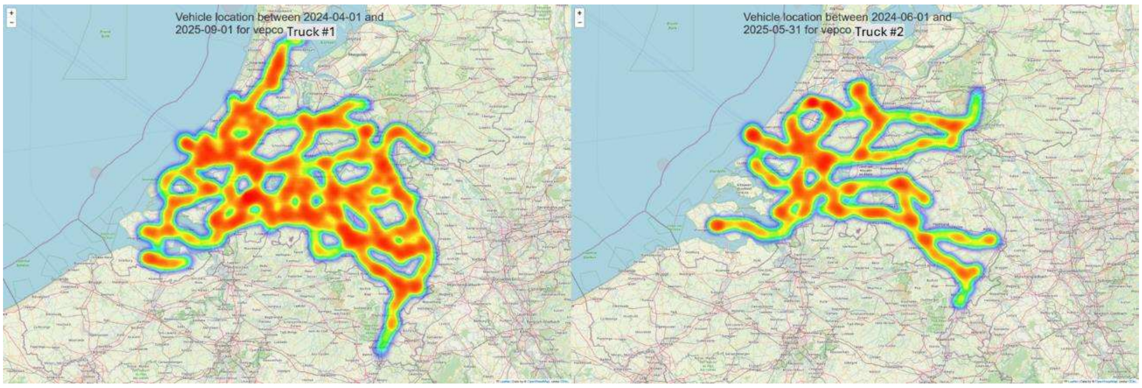

Figure 12: Heatmaps for locations of the VEPCO e-trucks

4.2 e-Truck specifications: Volvo FH and FM Electric

The Volvo FH 42T and FM 42T Electric are battery electric heavy-duty trucks designed for road freight applications, configured as 4×2 tractor units (Figure 13), with similar performance. The FM is designed for more mixed use (regional/short haul), whilst the FH is designed for long-distance freight. The FM is slightly smaller with lower roofline options, whilst the FH is larger and more ergonomic cabin for long-haul use.

Figure 13: Volvo FM Electric [5] and FH Electric [6] as representative in the MAGPIE fleet

The FH 42T and FM 42T Electric are equipped with a three-motor electric powertrain coupled with a 12-speed I-Shift automated gearbox, with the possibility of having only 2 motors on the FM model. The available battery configurations provide a total energy capacity of up to 540 kWh, based on 90kWh modules. See Table 4 for an overview of the driveline specifications. All batteries are NCA lithium-ion [7] and the modules are mounted to the chassis frame. The charging options are compatible with AC (43 kW unit supplied) and DC (up to 250 kW); full charging time ranges from 2.5 h (DC) to 9.5 h (AC).

Table 4: Volvo FH and FM Electric driveline overview

Component	Specification
Electric Motors	3 × permanent magnet (NEM3)
Gearbox	I-Shift 12-speed (EPT2412)
Battery Capacity	450 kWh (ESS450K)

Optional Capacity	540 kWh (ESS540K)

This configuration enables operation in typical regional distribution tasks, with a range of up to approximately 300 km depending on payload and environmental conditions, according to manufacturer specs.

Both vehicles (FH-FM) have similar dimensions, with a wheelbase of approximately 3800-3900 mm and a total chassis length of around 6180-6280 mm. The distance from the motor axle to the rear of the cab is 2384 mm for the FH and 2845 mm for the FM. In terms of manoeuvrability, the FH offers a turning diameter of 13.7 m between curbs and 15.0 m between walls, while the FM has a slightly larger turning circle of 14.0 m and 15.4 m respectively [8].

For the FME, the total unladen mass (tare) of the chassis is 9860 kg, distributed as 6010 kg on the front axle and 3850 kg on the rear axle(s). For the FHE, the total unladen mass (tare) of the chassis is 9900 kg, distributed as 6225 kg on the front axle and 3675 kg on the rear axle(s) [9]. Load ratings are shown in Table 5 below.

Table 5: Volvo FH/FM vehicle weight limitations [8] [9]

Parameter	Legal Limit	Technical Limit
Maximum Total Weight (MTT)	18,000 kg	21,500 kg
Maximum Combination Weight (MTC)	40,000 kg	44,000 kg
Front Axle Load	8,000 kg	8,500 kg
Rear Axle Load	11,500 kg	13,000 kg

5. Demonstration

5.1 Data collection

Each e-truck is equipped with a telemetry system, including a data logger and sensors, which record time-series measurements and event-based information. Periodically, this data is streamed to a cloud service, which typically is proprietary of the OEM.

In this project, the data was collected via Volvo Connect, the proprietary fleet management and data sharing platform from Volvo Truck. Access to this portal environment was granted by the e-truck owners through dedicated access credentials. In Volvo Connect, two types of data are of specific interest:

1. *Detailed*, a dataset where signals are recorded at roughly a 1-minute frequency and events are recorded based on trigger (such as key-off, key-on etc.).
2. *Ensembled*, a dataset that records cumulative data over a 24-hour period, making these available as one datapoint per field per day, typically used for daily, weekly or monthly periodical reports.

The following tables (Table 6 and Table 7) show some of the data collected and sampling times. The tables only highlight some of the signals that were used in the analysis.

Table 6: *Detailed* Dataset example of Signals

Signal	Approximate Frequency
Distance	1 / min
Speed	1 / min
Vehicle weight indication	1 / min
GPS (lat, lon)	1 / min
SOC	1 / min
Charge process	Event Based; 1/h

Table 7: Ensembled Dataset example of Signals

Signal	Common Frequency
Daily energy consumed	1 / day
Daily charged energy	1 / day
Daily motor energy	1 / day
Daily aux 24V energy	1 / day
Daily distance	1 / day

5.2 Data processing

Data (*detailed, ensembled)* is taken automatically from the source, the OEM data portal (Volvo Connect), and collected in a secured TNO database. The data is then queried (requested) by the user via an Application Programming Interface (API) in a post-processing and analysis environment (like Python or MATLAB). The required data can then be processed via scripts that have the following functions:

1. Pre-processing of data: involving all operations that involve filtering, manipulating or correcting to overcome the inherent issues of the datasets like missing data, erroneous sensor readings.
2. Processing the data: calculating, filtering, and manipulating the large data sets to provide more depth to the analysis, for example, calculating KPIs, cumulative values, average values, etc.
3. Presenting and reporting data: creating images, slides, KPI tables and report format.

In general, the pipeline was configured such that it could be used flexibly to query the data of choice and create informative content as requested.

5.3 Data presentations: Monthly E-Truck Reporting

On a monthly basis, all logistic operators were informed on the performance of their e-truck through a 'monthly report', a collection of infographic slides in PDF format, detailing the operations of the e-truck and metrics of importance to the operator, such as:

1. Distance travelled, energy consumed, average energy consumption/km, etc. (*Cumulative KPIs*).
2. Trip lengths, frequencies, etc. (*Trip information*).
3. Charging times, charging events, slow or fast charging (*Charging information*).
4. Energy per kilometre, components of total energy consumption, etc. (*Energy consumption).*

Figure 14 presents a single slide example with one week of operational conditions of location, speed and SOC.

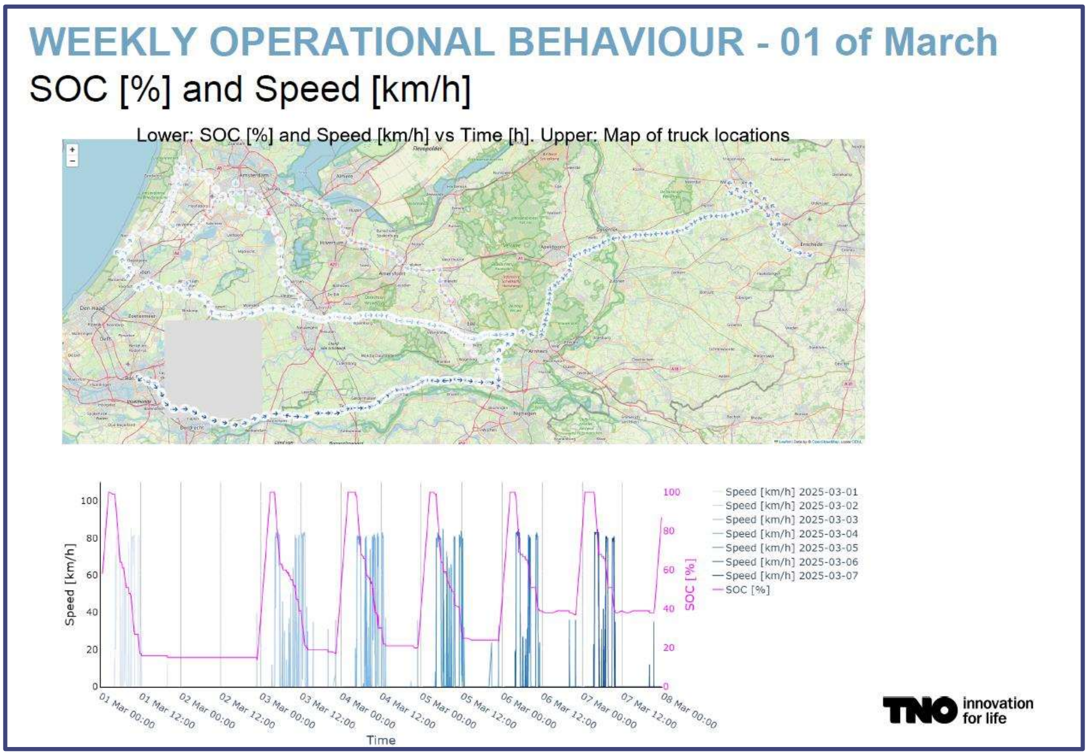

Figure 14: Example Slide of a Monthly Report

Roughly, a total of 120 Monthly Reports in a form of a presentation were shared annually, depending on actual e-truck start and some periods of data service interruption. Most logistic operators received more than 1 years' worth of monthly reports, depending on the actual duration of participation.

The monthly reporting operations were run using the data processing operations listed in Section 5.2, on a virtual/remote machine accessible through the cloud. The full automation of the process, via automatic launching of the monthly reporting pipeline, including dissemination towards fleet owners, was achieved.

6. Monitoring results

6.1 Logistics

Across the logistics operators deploying the **10 e-trucks** of the MAGPIE fleet, **354 tonnes of CO_{2e}** were avoided over a total of more than **0.9 million kilometres** across the regions of the Netherlands, resulting in an operational reduction of **44%** in GHG emissions.

Table 8 through Table 11 list, per e-truck (anonymized), the various KPIs that are the findings of the successful completion of the demonstration and the achievement of emission reductions through electric trucking.

Table 8: Results for KPI list 1

E-Truck		Active [year, month]	Total Distance [km]	Total Energy Charged [kWh]	(average) Energy Consumption [kWh/km]
#1	Volvo FME	2yr+3m	121424	164603	1.36
#2	Volvo FHE	1y+3m	67754	85095	1.31
#3.1	Volvo FHE	5m	25141	30837	1.32
#4	Volvo FME	2y+2m	58313	85930	1.49
#5	Volvo FHE	1y+7m	109608	129995	1.21
#6	Volvo FHE	1y+8m	145394	181232	1.28
#7	Volvo FHE	1y+8m	117101	151671	1.32
#8	Volvo FHE	2y+4m	141443	180785	1.32
#3.2	Volvo FHE	10m	15310	20317	1.41
#9	Volvo FME	1y+5m	100869	127382	1.34
#10	Volvo FME	1y+3m	30546	35686	1.28
Total/Average			932903	1193533	1.28

Across all trips, the e-trucks consumed around **85%** of the total energy demand for **driving** (motor consumption), with the remaining demand was split between low voltage loads (7%) related to for instance lights, instrument cluster, controllers and wipers, and high voltage loads (7%) related to e.g. cabin heating. Brake energy recuperation contributed to lowering the total energy demand by around 12%. Each e-truck on average drove with a combination weight of **26.2 tonnes** (e-trucks with trailer chassis are around 18tonnes) and an average speed of **34.7 km/h**.

Table 9: Results for KPI list 2

E-Truck		Energy: Motor [%]	Energy: AuxLV [%]	Energy: AuxHV [%]	Average combined weight [ton]	Average driving speed [km/h]
#1	Volvo FME	86	7	6	28.9	30.1
#2	Volvo FHE	85	7	7	27.7	34.4
#3.1	Volvo FHE	88	8	4	29.5	34.6
#4	Volvo FME	78	12	10	19.6	16.7
#5	Volvo FHE	86	7	6	26.2	36.1
#6	Volvo FHE	88	6	5	27.2	40.0
#7	Volvo FHE	87	6	7	27.4	38.4
#8	Volvo FHE	86	7	6	25.8	31.4
#3.2	Volvo FHE	85	8	6	27.0	29.4
#9	Volvo FME	83	7	9	25.2	37.3
#10	Volvo FME	79	8	6	25.8	30.6

The e-trucks drove, on average, **280 km** per day and **150** km between each charge. The majority of the trucks do not utilize the full range of the truck every day, with only a few trucks requiring multiple charging events to recharge the battery, cumulatively depleting the energy of the battery at least once a day, highlighting an extensive and multi-faceted usage. One full cumulative battery discharge is defined as a cumulative amount of energy depleted from the battery equal to that of the full capacity (e.g. 540Wh). In some cases, multiple charging events occur even when the e-truck does not require the full battery energy daily, highlighting a use of charging to top-up the battery opportunistically.

Table 10: Results for KPI list 3

E-Truck		Distance travelled per day. [km]	Avg. Distance between charges [km]	Avg. Number of cumulative full battery discharges [-]
#1	Volvo FME	220	139	0.82
#2	Volvo FHE	256	161	0.88
#3.1	Volvo FHE	244	179	0.82
#4	Volvo FME	121	98	0.67
#5	Volvo FHE	274	163	0.99
#6	Volvo FHE	335	146	1.28
#7	Volvo FHE	326	143	1.20
#8	Volvo FHE	266	98	0.95
#3.2	Volvo FHE	210	213	0.73
#9	Volvo FME	299	134	1.22
#10	Volvo FME	254	128	0.99
Average		255	145	0.96

Most e-trucks started operations on a working day at full charge (**~98%SOC**), and finished with a full recharge, starting above 20%SOC. All e-trucks never reached low charge (<20%) during any moment of the demonstration, indicating decision making to prevent stranding (highly inconvenient and costly) and leaving potential for charge scheduling and logistics optimization.

Table 11: Results for KPI list 4

E-Truck		Average number of charges per day	Average starting SOC [%]	Average minimum SOC [%]
#1	Volvo FME	1.36	97.0	29.9
#2	Volvo FHE	1.35	98.6	34.8
#3.1	Volvo FHE	1.33	96.7	27.8
#4	Volvo FME	1.10	96.8	47.9
#5	Volvo FHE	1.61	96.0	41.7
#6	Volvo FHE	1.93	91.2	23.1
#7	Volvo FHE	1.85	92.6	30.0
#8	Volvo FHE	1.80	98.1	27.7
#3.2	Volvo FHE	1.32	94.7	31.3
#9	Volvo FME	2.17	94.1	28.2
#10	Volvo FME	1.62	84.4	36.9
Average		1.59	94.6	32.7

6.2 Emissions

Emissions are common to all transportation modes. Pollutant emissions and regulation have been dominating technology development of all means of transport since the 1970s with the on-road sector being the primary sector to lead innovations. The current in-effect framework for pollutant emissions is Regulation (EC) 595/2009 [10] with Regulation 2024/1257 [11] as most recent amendment for emissions and battery durability (EuroVII). With growing attention to global warming, new regulations increasingly encompass greenhouse-gas (GHG) emissions, expressed in CO_2-equivalent (CO_{2e}). This provides an additional driver and framework for zero-emission technology development and creating a more level playing field with common goals and conditions. In the EU, this is shaped by the "Fit-for-55" package [12], which aims to reduce the net GHG emissions by at least 55% by 2030 when compared to 1990 levels. The governing CO_2 framework is established by Regulation (EU) 2024/1610 [13].

As part of the e-truck demonstration evaluation, a comparison of GHG (Section 6.3) and typical pollutant emissions (Section 6.4) is made to assess current savings and the outlook on further needs.

6.3 Greenhouse Gas or CO_{2eq} emissions

All e-trucks operate with zero local emissions, i.e. zero "tank"-to-wheel (TTW) emissions. Nevertheless, the total GHG emissions are non-zero, due to the non-zero GHG emissions of the electricity production. A comparison of GHG emissions is made between conventional diesel trucking and electric trucking, by using emission factors to calculate the emissions of the electric and diesel trucks, in the scenario that the exact same logistic operations were executed.

The emissions for each truck were calculated based on emission factors presented by the Dutch Emission Registry and the Joint Research Centre (JRC). The Dutch Emission Registry gives insight into the tank-to-wheel (TTW) emissions while the JRC data is used to derive the well-to-tank (WTT) emissions. Based on the total distance driven by each truck and the total energy charged, as listed in Table 8 and the emission factors listed in Table 12 below, the total emissions from each of the trucks can be calculated. The three specific pollutants considered in this study are the well-to-wheel (WTW) CO_2 emissions, tank-to-wheel (TTW) NO_x and particle emissions, the latter expressed in both PM_{10} and $PM_{2.5}$.

Table 12: GHG calculation factors for diesel and electric trucks

Element	Value	Source
DIESEL assumptions:		
Emission factor TTW [g/km]	627.8163	The Dutch Emission Registry [14]
Specific energy density [MJ / l]	36.90	https://www.acea.auto/fact/differences-between-diesel-and-petrol/
Fuel consumption of truck [km / l]	2.941	Panteia TCO tool [15]
CO_2 content WTT [g/MJ]	18.90	https://publications.jrc.ec.europa.eu/repository/handle/JRC119036 (JEC_WTTv5_ Appendix 1_Pathways 1_Oil and Gas.xlsx)
ELECTRICITY assumption:		
Emission factor WTT CO_2 [g/MJ]	105.4	https://publications.jrc.ec.europa.eu/repository/handle/JRC119036 (JEC_WTTv5_ Appendix 1_Pathways 6_Electricity.xlsx)

For the calculation of WTW CO_2 for diesel, the following formulae were used:

$$CO_2\ (WTW) = CO_2(TTW) + CO_2(WTT)\ [1]$$

$$CO_2(TTW)\,[ton] = km\ driven_{total} * diesel\ emission\ factor\ TTW/1e6$$

$$CO_2(WTT)\,[ton] = diesel_{total} * energy\ density_{diesel} * emission\ factor\ WTT/1e6$$

$$diesel_{total}[l] = km\ driven_{total}\ /\ fuel\ consumption_{diesel\ truck}$$

$$CO_2\ (WTW)[ton] = km * \left(EF\ TTW + \frac{energy\ density\ diesel}{consumption} * CO_2\ content\ WTT\right)/1e6\ \ [2]$$

For the calculation of WTW CO_2 for electric trucks, the following calculation was done:

$$CO_2\ (WTW)[ton] = energy\ charged_{total} *\ electricity\ emission\ factor\ WTT\ /\ 1e6$$

Following the European grid-mix as the basis for calculating the WTT CO_2 emissions for electricity (as mentioned in Table 12), it is found that the electric trucks, on average, produce **44%** less CO_2 than diesel trucks during operation. The results further highlight the benefits of utilizing an electric truck to cut greenhouse gas emissions. Importantly, this demonstrates how, to improve the sustainability of on road logistics, substantial effort must be made hand-in-hand to reduce the carbon intensity of the grid by increasing the penetration of low-carbon power generation such as solar, wind, hydropower, etc.

Figure 15 and Table 13 show the total CO_{2eq} that was produced by each truck in the demonstration. This is purely in proportion to the number of kilometres driven by each truck for the diesel case. Table 13 shows the emissions avoided by running operations with an electric truck instead of its diesel equivalent. Over the entire duration of this project, **354 tons** of CO_2 were avoided by operating with e-trucks. This number is based on the grid mix in Europe, which is roughly valid for the Dutch grid mix in 2024. Using the specific emission factors for diesel fuel and electricity production in the Netherlands, as available through [16] for various years, would of course give slightly different values. In the Netherlands, a 54% sustainable power generation was realized in 2024 and the ambition for 2030 is at 75% renewable energy source. The IEA Energy Policy Review [17] even indicates close to a 100% may be realized in the Netherlands by 2030, mainly by wind, solar and biosources. That would certainly yield a lower carbon intensity for electricity generation and further boost the environmental performance of e-trucks.

It should also be noted that no energy source is entirely free of CO_2 emissions as there is always life cycle CO_2 involved in the production and construction of even the most sustainable ways of energy production. As a result, the total carbon intensity will very unlikely yield an exact zero. Including the additional production, construction and dismantling CO_{2eq} more common for Life Cycle Analysis (LCA) was considered beyond the scope of this study and is hence not further explored here.

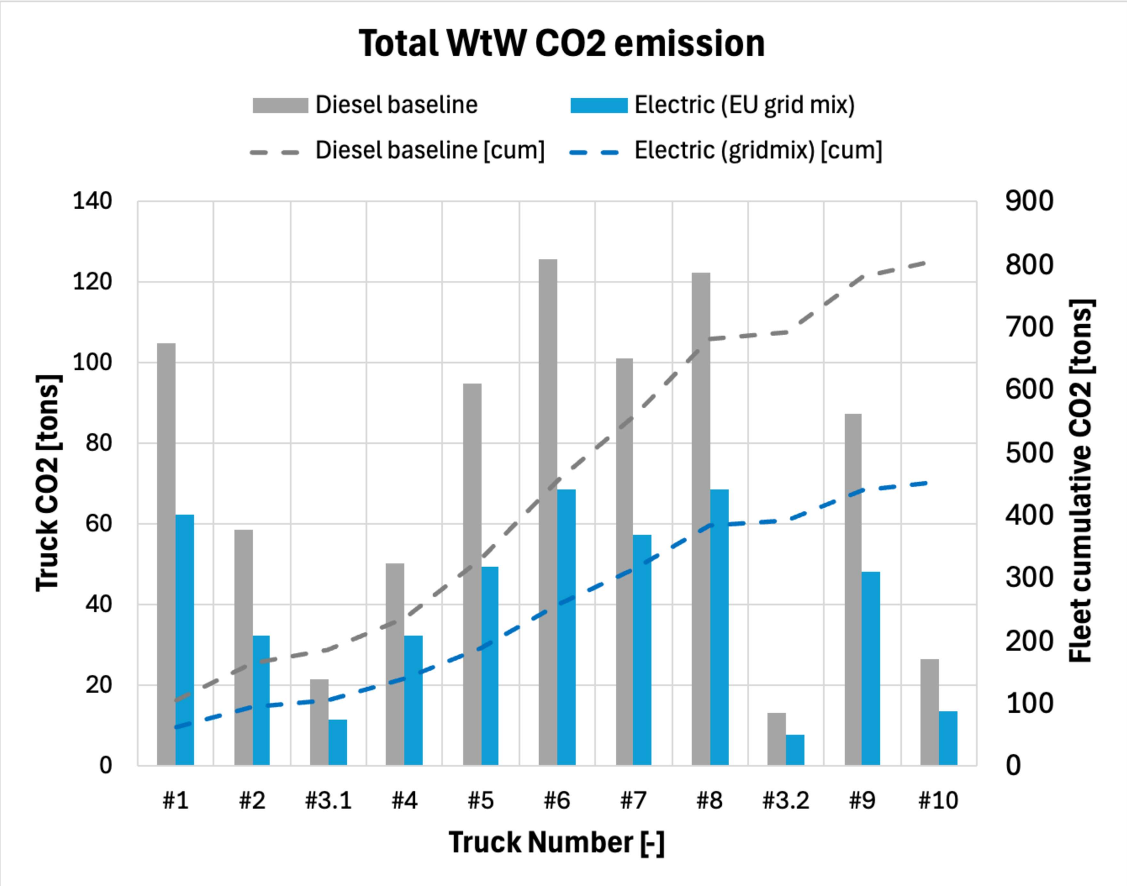

Figure 15: Total WTW CO_2 emission per truck per transporter.

Table 13: CO2eq emission comparison for e-truck and baseline diesel truck

E-Truck		Diesel WTW CO_2 [ton]	Electricity WTW CO_2 [ton]	Total WTW CO_2 avoided [ton]
#1	Volvo FME	105.0	62.5	42.6
#2	Volvo FHE	58.6	32.3	26.3
#3.1	Volvo FHE	21.7	11.7	10.0
#4	Volvo FME	50.4	32.6	17.8
#5	Volvo FHE	94.8	49.3	45.5
#6	Volvo FHE	125.8	68.8	57.0
#7	Volvo FHE	101.3	57.6	43.7
#8	Volvo FHE	122.3	68.6	53.7
#3.2	Volvo FHE	13.2	7.7	5.5
#9	Volvo FME	87.2	48.3	38.9
#10	Volvo FME	26.4	13.5	12.9
Total		806.9	452.9 (-44%)	354

6.4 Pollutant emissions: Nitrogen Oxides (NO_x) and Particulate Matter (PM)

In addition to the GHG effects, it is also necessary to assess the impact of e-trucks on typical pollutant emissions of road applications when comparing against the diesel equivalent. These commonly more local emissions are NO_x and PM. These pollutants are especially responsible for health and environment issues [18]. NO_x is a more regional pollutant while PM is more a local pollutant. The latter is specifically hazardous to health as fine particles may enter the lungs.

E-trucks are the obvious choice to avoid NO_x emissions since there is no fuel burned and hence no NO_x is produced. The Dutch Emission Registry provides an emission factor for diesel trucks. These values can be seen in Table 15. Based on these values, the total NO_x emissions can be calculated using the total (truck) kilometres. This can be seen in Figure 16. Note that this comparison is at vehicle tailpipe (TTW) level and potential NO_x from electricity production is not taken into account.

Table 14 shows that there were 1921 kg of NOx emissions avoided during the demonstration period of this project by utilizing e-trucks. E-trucks are therefore an obvious choice for avoiding NOx emissions.

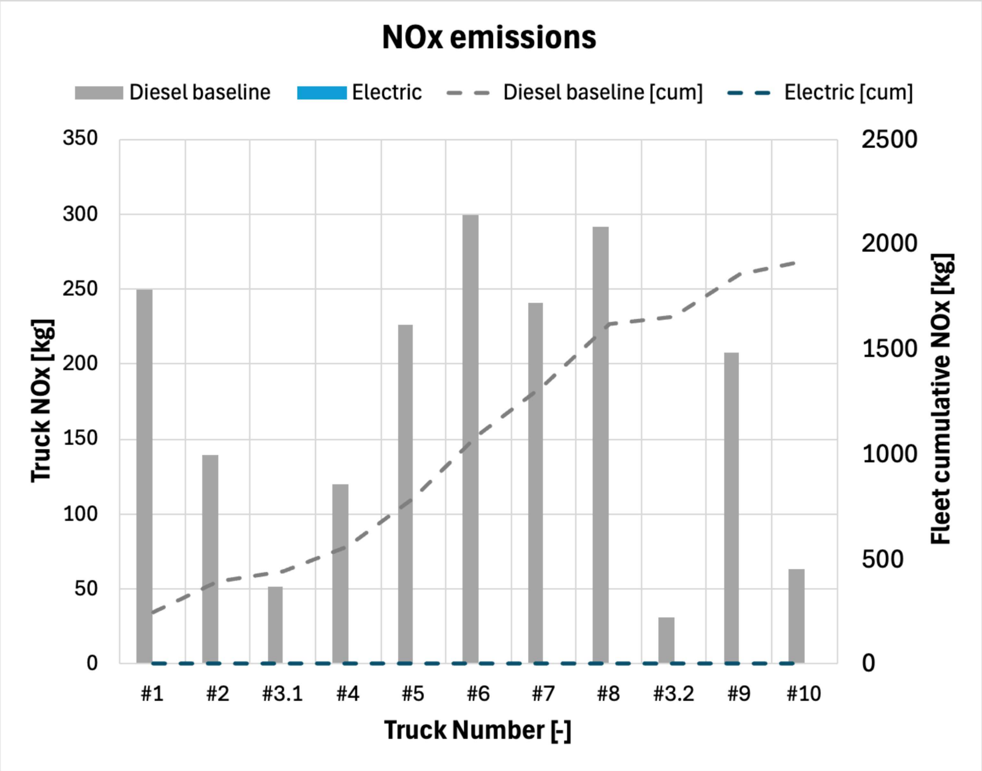

Figure 16: Total NOx emissions per transporter. These emissions are derived from the total kilometres driven by the e-trucks.

Table 14: NOx emission comparison for e-truck and baseline diesel truck along with the emissions avoided.

E-Truck		Diesel NOx [kg]	Electric NOx [kg]	Total NOx avoided [kg]
#1	Volvo FME	250.0	0	250.0
#2	Volvo FHE	139.5	0	139.5
#3.1	Volvo FHE	51.8	0	51.8
#4	Volvo FME	120.1	0	120.1
#5	Volvo FHE	225.7	0	225.7
#6	Volvo FHE	299.4	0	299.4
#7	Volvo FHE	241.1	0	241.1
#8	Volvo FHE	291.3	0	291.3
#3.2	Volvo FHE	31.5	0	31.5
#9	Volvo FME	207.7	0	207.7
#10	Volvo FME	62.9	0	62.9
Total		1921.1	0 (-100%)	1921.1

For calculating the Particulate Matter (PM) emissions, a similar approach to the NO_x emissions was adopted, where the emission factors were derived from the Dutch Emission Registry and the total kilometres were used as a basis to calculate total emissions. In terms of PM, there are -of course- no engine tailpipe emissions in the e-truck, yet there are still some emissions from the road, tyre and brake. For road, tyre and brake related PM, two measurement cut-off criteria are used. Note that PM_{10} automatically includes the $PM_{2.5}$ share. The applicable emission factors can be found in Table 15.

Table 15: Particulate Matter Emission Factors as derived from the Dutch Emission Registry

Fuel	PM_{10}-exhaust [g/km]	PM_{10} [g/km]	$PM_{2.5}$ [g/km]
Diesel EuroVI	0.0112	0.0734	0.0125
Electricity	0	0.0734	0.0125

The total PM emissions of the truck (again considered as TTW part) are derived from the total kilometres driven by the individual trucks. For each truck, PM is calculated as the summation of the exhaust and the tyre/road/brake emission values.

As reflected in Figure 17 and Table 16, the total, electric trucks produce 13% less PM_{10} and 47% less $PM_{2.5}$ when compared to equivalent EuroVI diesel trucks. The emission reduction all comes from the avoided tailpipe emissions.

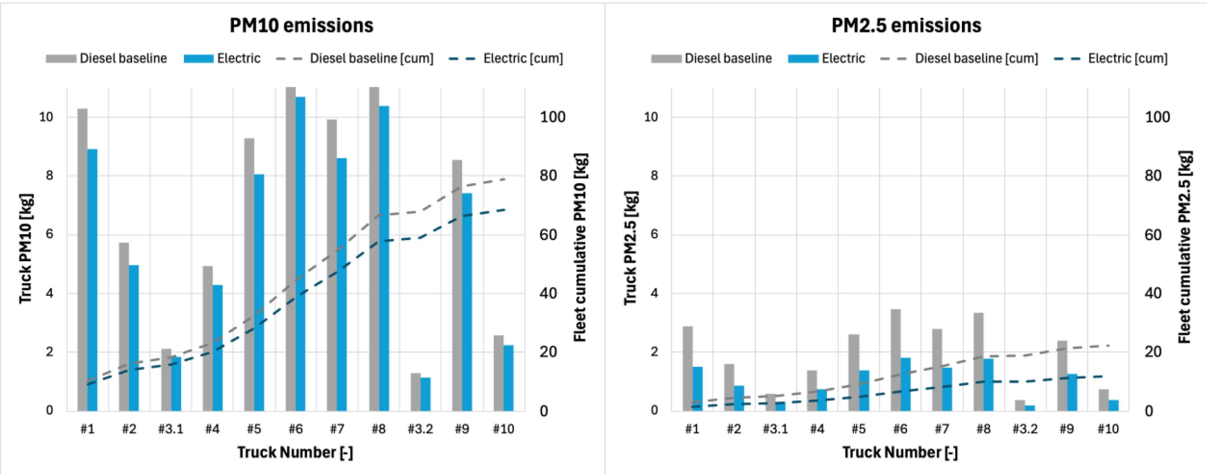

Figure 17: Total PM_{10} and $PM_{2.5}$ emissions per truck.

Although tyre, road and brake emission factors are assumed to be the same for the diesel and e-trucks, in several interviews with the transportation companies (Section 7.1), it was mentioned that the tyre life for e-trucks is shorter than their diesel counterpart. This is assumed to be due to the slightly higher empty weight of the electric tractor unit, its higher torque response, acceleration and the regenerative braking capability acting on the driven axle. At the same time, this this regenerative braking function should reduce and relieve the wear of the brake pads and lower these specific brake emissions. The overall impact on the shift of total PM emissions is yet to be discovered and a topic of ongoing research and investigation.

Table 16: PM_{10} and $PM_{2.5}$ emission comparison for e-truck and baseline diesel truck along with the emissions avoided.

E-Truck		Diesel PM_{10} [kg]	Diesel $PM_{2.5}$ [kg]	Electric PM_{10} [kg]	Electric $PM_{2.5}$ [kg]	Total PM_{10} avoided [kg]	Total $PM_{2.5}$ avoided [kg]
#1	Volvo FME	10.3	2.9	8.9	1.5	1.4	1.4
#2	Volvo FHE	5.7	1.6	5.0	0.8	0.8	0.8
#3.1	Volvo FHE	2.1	0.6	1.8	0.3	0.3	0.3
#4	Volvo FME	4.9	1.4	4.3	0.7	0.7	0.7
#5	Volvo FHE	9.3	2.6	8.0	1.4	1.2	1.2
#6	Volvo FHE	12.3	3.4	10.7	1.8	1.6	1.6
#7	Volvo FHE	9.9	2.8	8.6	1.5	1.3	1.3
#8	Volvo FHE	12.0	3.4	10.4	1.8	1.6	1.6
#3.2	Volvo FHE	1.3	0.4	1.1	0.2	0.2	0.2
#9	Volvo FME	8.5	2.4	7.4	1.3	1.1	1.1
#10	Volvo FME	2.6	0.7	2.2	0.4	0.3	0.3
Total		78.9	22.1	68.5 (-13%)	11.7 (-47%)	10.4	10.4

7. Impact on logistics operations

During the MAGPIE project, several interviews were conducted with representatives of the transportation companies to discuss various aspects of e-truck adoption, among which the feedback on the monitoring data. For most participants, the vehicles that were monitored were the first e-trucks to be used in daily operations. This section will generically describe the common experiences and challenges that were encountered.

The number of participants is too small to tell if these experiences are representative of all e-truck operators for container transportation in and around European port areas. The results presented here give more context to the measurements and calculations found elsewhere in this report where readers have to take the remark about representativeness into account. Related to the topic of representativeness, it is important to mention that the demonstration has focussed on a specific transport segment that is very relevant for the Port of Rotterdam and that still has some severe challenges related to electric driving: container transport with heavy duty trucks (tractor-trailer combinations) to and from the Port of Rotterdam over relative larger distances (about 100 km or even more). This segment is very different compared to other transport segments such as (inner) city logistics with smaller trucks or vans, many drops and shorter trip distances where the electrification of transportation has already been introduced for quite some time and uptake has higher presence.

7.1 First impressions

In general, the e-trucks themselves and the recharging equipment functioned as expected, and no large problems were reported by the companies that were interviewed.

The drivers who use the e-trucks are happy with them. The e-trucks are comfortable and quiet due to the lack of a combustion engine, and drivers enjoy the instant torque from the electric drivetrain. They also report getting enthusiastic reactions from the public and customers who see the e-trucks.

The following limitations of e-trucks were reported by the MAGPIE fleet truck owners:

- Not all truck drivers are willing to drive an e-truck –at the beginning of the demonstration, some only want to drive diesel-powered vehicles. Among reasons are age close to retirement and not wanting to try and experience something new, yet also some young starters stated to prefer the sound of the engine.
- The e-trucks have a limited range and long recharge time relative to a diesel truck.
- No ADR-compliant (dangerous goods) trucks are available yet. Additionally, likely due to lack of ADR qualification, clients may not allow the entrance of E-trucks as part of their current (safety) policy. Therefore, dangerous goods assignments are still difficult.
- At the time of the project, no low-deck options were available, so not all trailer types could be used for transportation.
- Truck tyres are said to wear out quicker and need early replacement, especially on the driven axle. High direct torque from the electric motor on drive and brake regeneration as well as the higher (average) axle load are likely cause for this inconvenience.

The planners reported that they select work for the electric trucks where their shortcomings are not a hindrance to efficient logistics. This is possible because the truck owners' fleets consist predominantly of diesel vehicles, with only one or two electric vehicles.

7.2 Recharging

Diesel trucks can be refuelled whenever needed, with drivers deciding where and when to refuel. Since refuelling is quick and easy and fuelling stations are widely available, planners do not even take refuelling into consideration. For e-trucks, this is very different. Fully recharging a truck battery takes anywhere from a few hours to half a day, depending on the availability of charging infrastructure and the properties of the battery and charger. This means scheduling (partial) charging is an important part of truck planning.

Most trucks charge during the day one or more times (see Figure 18). This is done to be flexible – charging when the opportunity presents itself means the e-truck is ready for (planned or unplanned) longer trips after charging. Another important reason for charging during the day is to allow drivers to drive the full 10 hours permitted by EU law. Many drivers count on these hours to make the additional income they need and are upset when the e-truck battery runs out early and prevents such long working days.

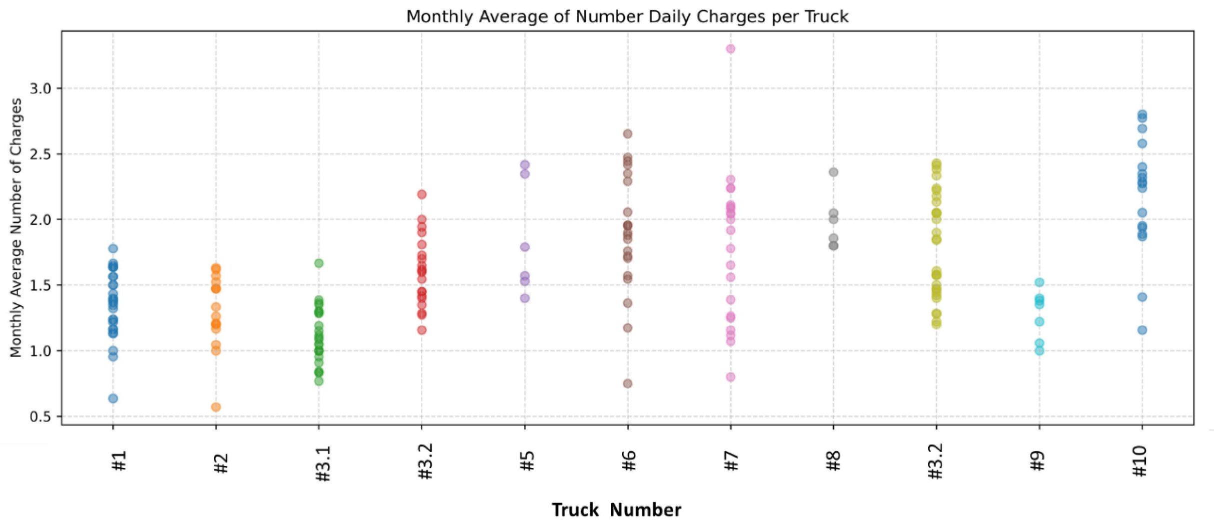

Figure 18: Number of charging events in a day - monthly average.

Charging strategies employed include:

- Overnight charging
- Charging during mandatory driver breaks
- Charging at customer site during (un)loading
- Charging at own site during (un)loading
- Charging at public charging locations

All companies charge their e-trucks preferably at their 'home base' (see Figure 19). The charging strategy of individual companies is defined by their preferences, the type of transport they have and the possibilities to apply different charging strategies mentioned above. Each company adapts its charging strategy according to operational requirements and available infrastructure.

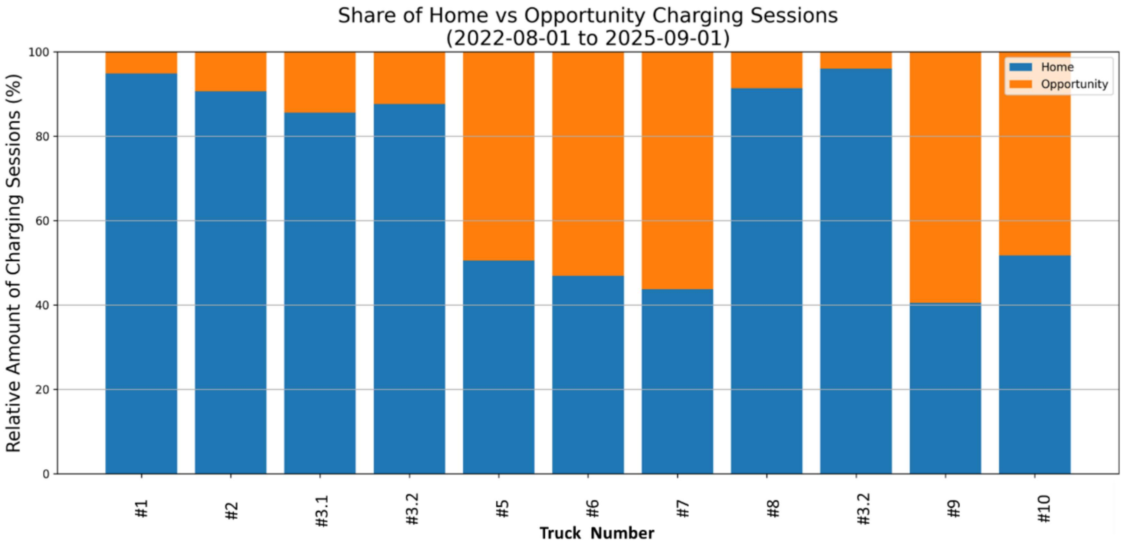

Figure 19: Distribution of charging at home/preferred base and at other locations

7.3 Influence on logistics operations and planning

Planning of e-trucks is more complex than diesel trucks, because battery state of charge and expected available range must be taken into account. Planners not only need to look at time needed for driving, working and mandatory breaks, but also at the charge left in the battery and time, price and location for (partial) recharging. Planners for companies in this project spent a lot more time on planning the e-trucks than for diesel trucks.

To reduce planning complexity, some e-trucks are scheduled on fixed and optimized routes. Some e-trucks also mainly drive short trips close to the 'home base', so they are always able to recharge when needed and are able to charge for a more favourable price.

Sometimes operations are adjusted to the needs of driving e-trucks. For example, one of the companies unloads its e-truck while it is standing at the charger, which is located on the same container terminal, to save the e-truck moving time. To do so, they need the reach stacker from the container terminal to come to the truck/trailer, so this solution would be unworkable when many e-trucks had to be (un)loaded this way. For the time being, it provides a workable operational solution.

7.4 Costs

For all companies in this project, the current e-trucks are more costly to own and operate than diesel trucks. The companies that were interviewed said it is difficult to find customers willing to pay more for the currently more expensive electric transportation. Some have a single client willing to pay more, others pay out of their own pocket as an investment in sustainability. Another may have a client that can supply electricity for recharging on their site. Such options may change how the transport contracts need to be defined and reflect a change in business models of the transport unit (truck, trailer) by excluding/exchanging the price of energy.

Companies report that prices at public charging facilities vary between €0.40 to €0.70 per kWh. For all of them, this is far more expensive than charging 'at home' where they typically have large industrial energy supply contracts in place for their terminals, warehouses and offices. The business case for e-trucks therefore becomes more unfavourable when public charging must be used.

7.5 Scaling up heavy duty battery-electric truck use

Across much of the Netherlands, the electricity grid is at or near maximum capacity ('grid congestion'), leaving many companies unable to expand connections or add chargers, and limiting simultaneous e-truck charging. Already, participants in this project are unable to install more chargers due to a lack of capacity on the electricity grid and reported being fined when they use multiple chargers at once due to exceeding their maximum allotted grid capacity. External charging locations are available but generally more expensive than depot charging, so routine reliance on them is limited due to higher energy costs.

Logistics is a very competitive industry, where thin profit margins are common (especially in the transport segment examined as in this demonstration). The companies in this project report the majority of their clients do not want to pay more for transportation with e-trucks. Successful upscaling of e-truck use will therefore depend on the TCO becoming equal to, or lower than, that of a diesel truck. For this to happen, three main developments must take place. First, e-trucks must become cheaper to buy. Second, the e-truck owners must be able to recharge them at competitive electricity prices. Finally, increasing the capacity of the battery would make planning of e-trucks easier and make daily utilization for more market segments suitable for transportation by e-trucks.

New e-truck models are expected to reach the market during 2025/2026 with a battery that stores more kWh and enough for a driving range of between 500 and 700 km. This is enough for most e-trucks to drive for a full working day without recharging. These new e-trucks are also prepared for the new e-truck charging standards using the Megawatt Charging System (MCS) standard, allowing charging times to be significantly reduced when high power chargers are available.

7.6 Conclusions

Currently, e-truck owners – especially in the container transportation business- are all still in an experimentation phase and mindset. They are willing to take some extra steps to integrate the e-trucks into their operations, such as selecting specific tasks, accepting lower earnings per trip, re-arranging operations to allow for opportunity charging, specially selecting drivers who are comfortable with electric vehicles, et cetera.

Cost of ownership, ability to recharge, operational planning, and limited range are still problematic. In spite of this, the e-truck owners are searching and implementing solutions (often ad hoc) to enable the successful usage of battery-electric vehicles in their daily operations. Barriers to upscale the adoption of e-trucks are:

- Limited battery capacity which causes range and planning problems,
- grid congestion which restricts the installation of e-truck chargers in many locations, and
- higher cost and lack of willingness of clients to pay more for electric transportation.

8. Lessons Learned

The deployment of e-trucks in the demonstration project shows the operational viability of battery-electric heavy-duty vehicles, while also revealing critical limitations and opportunities for improvement. These insights are essential for future deployments, guiding towards efficient allocation of resources to address successful deployment bottlenecks and refining future supporting infrastructure and practices.

8.1 Specific Challenges and Solutions Encountered by Logistic Operators During Deployment

Several barriers to large-scale adoption were identified across technical, infrastructural, and organizational domains:

- **Limited range and charging performance**: Current vehicle models offer a range that often constrains operations. High demand exists (especially in 4x2 configurations) for extended range and fast-charging capabilities.
- **Charging infrastructure limitations:**
    - Depot charging: Grid connection capacity at depots remains a bottleneck
    - Public charging: Operational reliability is inconsistent – chargers are sometimes out of service, costly, or incompatible due to varying charge point operators (CPOs) and contractual terms and conditions.
- **Service ecosystem immaturity**: Regional disparities in maintenance and repair capabilities were evident. Service times were longer due to a shortage of High Voltage-certified mechanics, typically two are required per vehicle, delaying diagnostics and repair turnaround.
- **Fleet deployment optimization**: Companies initially struggled to align vehicle capabilities with suitable routes and to identify reliable charging locations. This process required close coordination between drivers and the dispatchers of each logistic company, often involving conservative planning practices (e.g. completing trips with large SOC margins, or always starting shifts at 100% SOC).
- **Driver perceptions and adaptation**: While some drivers –especially younger ones– initially missed the sound and feel of ICE vehicles, most adapted quickly and appreciated the smoother, quieter ride. Companies adopting rotational driver pools reported improved acceptance and increased learning curves.
- **Charging behaviour**: Charging strategies varied widely. However, most companies did not yet implement smart charging practices, such as shifting charging to off-peak hours, modulating charging power, or only charging to the level needed for the next mission when additional charging opportunities are available later in the schedule.

9. Total cost of ownership

This chapter contains a comparison between the total cost of ownership (TCO) for a heavy-duty diesel truck and a heavy-duty battery-electric truck in the Netherlands. Naturally, each company must perform its own cost calculation given unique conditions for site location and operation. This chapter nevertheless provides a generalised single example calculation to illustrate the cost differences between diesel and heavy-duty battery-electric trucks (e-trucks), the impact of Dutch subsidies on these costs, and the conditions under which e-trucks can become cost-competitive with diesel vehicles.

9.1 Calculation method

To compare the costs of diesel and e-trucks, a Total Cost of Ownership was calculated for both types of vehicles. TCO is calculated per year and includes costs for capital expenditure (CAPEX) and operational expenditure (OPEX). The main categories of cost are listed in Table 17.

For this analysis, the *'TCO-ZET-Vracht'* model version 7.3 [15] was applied. This model was developed by consultancy company Panteia for the Dutch government initiative *'Topsector Logistiek'*. Some parameter values have been changed by TNO to more accurately reflect the situation at the time of writing.

A number of assumptions were required for the TCO calculation. While these values aim to provide a realistic approximation, they may vary significantly depending on market conditions, company characteristics, operational practices and other factors. The list of assumptions is given in Table 17. Many are the default settings in the model.

Table 17: Assumptions made for the example TCO calculation.

Assumptions diesel truck	Value	Unit
Purchase price	120.405,00	€
Remaining value after write-off period	27.693	€
Write-off period	7	years
Distance driven	70.000,00	km / year
Diesel price	1,78	€ / l
Diesel use	0,34	l/km
Assumptions e-truck		
Purchase price	353.284,00	€
AANZET Subsidy [19]	39.215,00	€
Remaining value after write-off period	81.255,00	€
Write-off period	7	years
Charger price (43 kW AC)	6.143,00	€
SPRILA Subsidy [20]	1.200,00	€
Distance driven	70.000	km / year
Electricity price (average)	0,22	€ / kWh
Electricity use	1,47	kWh/km
HBE [21] price	9,50	€ / HBE

9.2 TCO calculation current baseline: Example 1

Based on the Panteia model and assumptions as presented in Section 9.1, a TCO comparison between the conventional diesel reference truck and an e-truck was made. All cost elements as stated in the model are listed in Table 18 and shown in Figure 20.

Table 18: Example total cost of ownership calculation comparison for a heavy-duty diesel vs. heavy duty battery-electric truck (e-truck)

	Diesel	e-Truck	
	Heavy duty truck without trailer	**Heavy duty e-truck without trailer, with 540 kWh battery**	
		Subsidized	No subsidies
Fixed costs per year (a)	€ 9,547	**€ 21,650**	€ 22,415
Road tax	€ 1,028	€ 0	€ 0
Euro vignette	€ 1,250	€ 1,250	€ 1,250
Interest	€ 2,888	€ 7,709	€ 8,474
Insurance*	€ 4,297	€ 12,608	€ 12,608
Vehicle tax	€ 0	€ 0	€ 0
Various other vehicle costs	€ 84	€ 84	€ 84
Variable costs per year (b)	€ 69,931	**€ 53,748**	€ 71,400
Depreciation of vehicle	€ 13,245	€ 33,259	€ 38,861
Fuel consumption of vehicle	€ 43,830	€ 0	€ 0
Fuel consumption for cooling	€ 0	€ 0	€ 0
Electricity consumption	€ 0	€ 23,289	€ 23,289
Adblue consumption	€ 399	€ 0	€ 0
Tyres	€ 3,254	€ 3,254	€ 3,254
Maintenance	€ 6,415	€ 3,207	€ 3,207
Repairs	€ 1,654	€ 1,654	€ 1,654
Renewable Fuel Units (HBE)**	€ 0	*- € 12,051*	€ 0
Specific transport costs	€ 1,135	€ 1,135	€ 0
Charging system costs per year (c)	€ 0	**€ 3,936**	€ 4,056
Purchase and installation	€ 0	€ 494	€ 614
Operational costs	€ 0	€ 3,442	€ 3,442
Total vehicle and system (a+b+c) per year	€ 79,478	€ 79,334	€ 97,872
per km	€ 1.14	€ 1.13	€ 1.40

** Insurance costs are directly related to purchasing price and part of the TCO model calculation*
*** HBEs are paid to the energy supplier – this assumption is only valid when the truck owner supplies their own energy*

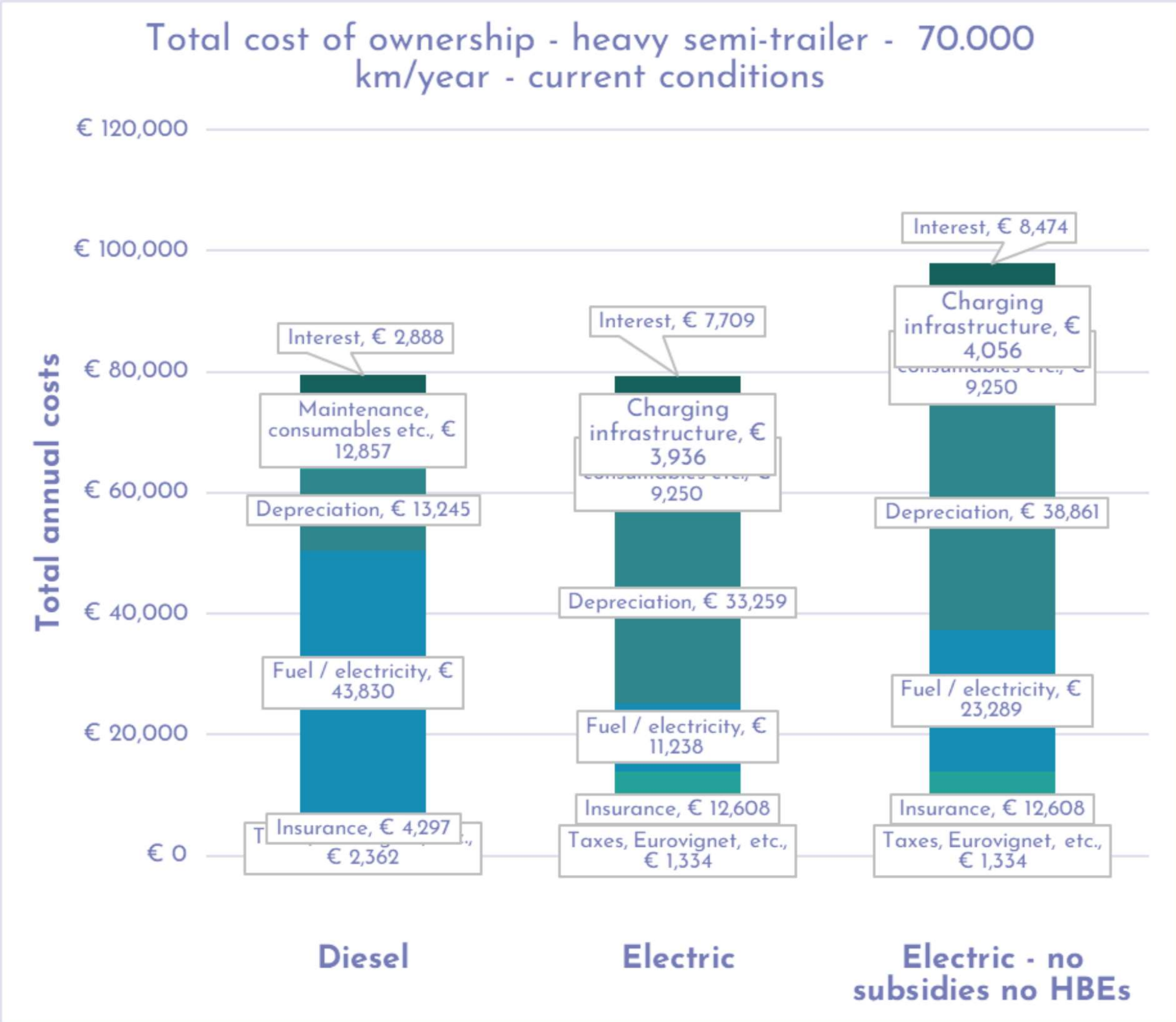

Figure 20: Total Cost of Ownership calculation Example 1, including breakdown of cost elements. Figures should be read as indicative. (left-to-right: diesel baseline, electric with subsidies, electric without incentives)

9.3 TCO differences between diesel and e-trucks

The main difference between battery-electric and diesel trucks is that battery-electric models are more expensive to buy, but cheaper to run (see Figure 20).

At the time of writing, in the Netherlands, the purchase price for an e-truck is roughly three times the price of a comparable diesel truck. Higher purchase prices lead to higher depreciation, higher interest payments, and higher insurance payments. This raises the TCO of e-trucks relative to those of diesel-fuelled trucks.

This higher CAPEX-related cost is (at least partially) offset by the electric vehicle's lower cost for energy use, depending of course on the electricity price paid at the charging location. The electricity price paid for charging varies considerably. Some trucks are able to use a private charger and pay the wholesale price for electricity, while public charging can be more expensive. In the TCO calculation example, the e-truck always charges for an average price of 0,22 €/kWh.

At the current truck purchase prices (excluding subsidies), diesel fuel and electricity prices, the diesel trucks have a lower Total Cost of Ownership. In the Netherlands, when benefitting from a number of different subsidies and selling Renewable Fuel Units (Hernieuwbare Brandstof Eenheden, or HBEs for short), this cost gap can be reduced to break-even as shown by this first example of the TCO calculation and its applied conditions.

A number of currently available Dutch incentives are included in the TCO calculation. These are:

SPRILA [20] – Dutch government subsidy that lowers the purchase price of charging infrastructure.

AANZET [19] – Dutch government subsidy that lowers the purchase price of an e-truck. This subsidy is only granted to a single truck purchase for the selected companies (total annual fund is limited). It is not possible to take benefit of this subsidy for multiple trucks at once. This subsidy therefore should not be taken into account when estimating the TCO for a larger number of e-trucks as needed for upscaling and accelerating the electrification of the transport.

MIA\VAMIL – Tax rules that allows companies to subtract investments in sustainable transportation from their profits. For a full explanation, please refer to the government website explaining this rule in detail [22]. This means the company benefits from a tax reduction. In the calculation model, the amount of taxes not paid is subtracted from the purchase price of the e-truck.

HBEs (Renewable Fuel Units) [21] – The Dutch government mandates that energy suppliers' hand over a certain amount of HBE (Hernieuwbare Brandstof Eenheden) certificates to the transport sector, related to the total amount of fuel they sell. If e-truck owners generate their own energy, for example from solar panels, and supply that energy to their own e-trucks, they will receive HBE certificates which they can sell to fossil fuel suppliers who need them. As such a trading system has been defined under the control of the government and with the intention to support sustainable energy use in transportation.

9.4 TCO calculation for upcoming changes in taxation: Example 2

The way trucks are taxed is about to change in the next two years. For the Netherlands, the new truck tax ('vrachtwagenheffing') system will be introduced in 2026. The ETS2 emissions tax, which applies to trucks in all of Europe, will be introduced in 2027. This section describes the expected effects of this change on the TCO comparison between diesel and trucks.

Dutch truck tax system "Vrachtwagenheffing"

From 2026, the Netherlands will tax trucks in a new way. This new system is called 'vrachtwagenheffing'. The 'Euro vignette' tax will disappear, and road taxes will be lowered. Under the new rule truck taxes are calculated based on the number of kilometres driven and the emission class for the vehicle. Some details of this policy, especially the price for the tax for different vehicle classes, are not yet known. The expected prices for the heaviest trucks (>32 tons) in 2026 are: 0,192€/km for a EuroVI+ diesel truck, and 0,038€/km for an e-truck. For a more detailed explanation and up-to-date price estimates for this tax, please refer to the Dutch government website detailing this policy [23].

Emissions Trading Scheme (ETS2)

Starting in 2027, companies selling fossil fuels in the EU must hand over emission certificates to cover the emissions caused by burning this fuel. This is expected to increase the fuel price, as fuel companies' suppliers pass on these costs to their customers. Research from CE Delft estimated a price of €40-€60 per ton CO_2 for an ETS2 certificate, which would translate to a price increase of 0,10 - 0,15€ per litre of diesel [24]. For electricity generation, the ETS is already in force. The ETS2 will therefore not affect electricity prices.

Estimated impact of new taxes.

Below Table 19 presents a second TCO example assuming these new taxes to be in place. The effect of the (Dutch) subsidies (AANZET, SPRILA, MIA, HBE) are shown as well for the e-truck.

Table 19: TCO example 2, assuming the Dutch "vrachtwagenheffing" and ETS2 are implemented.

	Diesel	e-Truck	
	Heavy duty truck without trailer	**Heavy duty e-truck without trailer 540 kWh**	
			With subsidies
Fixed costs per year (a)	€ 7,897	€ 21,793	€ 20,460
Interest	€ 2,888	€ 8,474	€ 7,140
Insurance*	€ 4,297	€ 12,608	€ 12,608
Vehicle tax**	€ 628	€ 628	€ 628
Various other vehicle costs	€ 84	€ 84	€ 84
Variable costs per year (b)	€ 86,358	€ 74,060	€ 64,291
Depreciation of vehicle	€ 13,245	€ 38,861	€ 29,092
Fuel consumption of vehicle	€ 43,830		
HBEs***			-€ 12,051
Vrachtwagenheffing	€ 13,440	€ 2,660	€ 2,660
ETS2	€ 2,987		
Electricity consumption		€ 23,289	€ 23,289
Adblue consumption	€ 399		
Tyres	€ 3,254	€ 3,254	€ 3,254
Maintenance	€ 6,415	€ 3,207	€ 3,207
Repairs	€ 1,654	€ 1,654	€ 1,654
Specific transport costs	€ 1,135	€ 1,135	€ 1,135
Charging system costs per year (c)		€ 4,056	€ 3,936
Purchase and installation		€ 614	€ 494
Operational costs		€ 3,442	€ 3,442
Total vehicle and system (a+b+c) per year	€ 94,255	€ 99,910	€ 76,636
km per year	70,000	70,000	70,000
Average cost per km	€ 1.35	€ 1.43	€ 1.09

* *Insurance costs are directly related to purchasing price and part of the TCO model calculation*
** Vehicle tax depends on the specifics of the vehicle involved. For more information, please refer to the official Dutch government website that explains the rules [25].
*** *HBEs are paid to the energy supplier – this assumption is only valid when the truck owner supplies their own energy.*

The average TCO price difference without additional supporting incentives (Table 19, Figure 21) is slightly larger than in the current situation (as in Section 9.2). When no subsidies are received, the diesel truck is still the cheaper option. When the purchase price is reduced, for example using current subsidy conditions, e-trucks can become significantly cheaper than diesel trucks. Keep in mind that this calculation depends on many variables and assumptions and is therefore meant as an illustration only. For each truck owner, the particular circumstances and taxes and subsidies in their own country will determine the TCO.

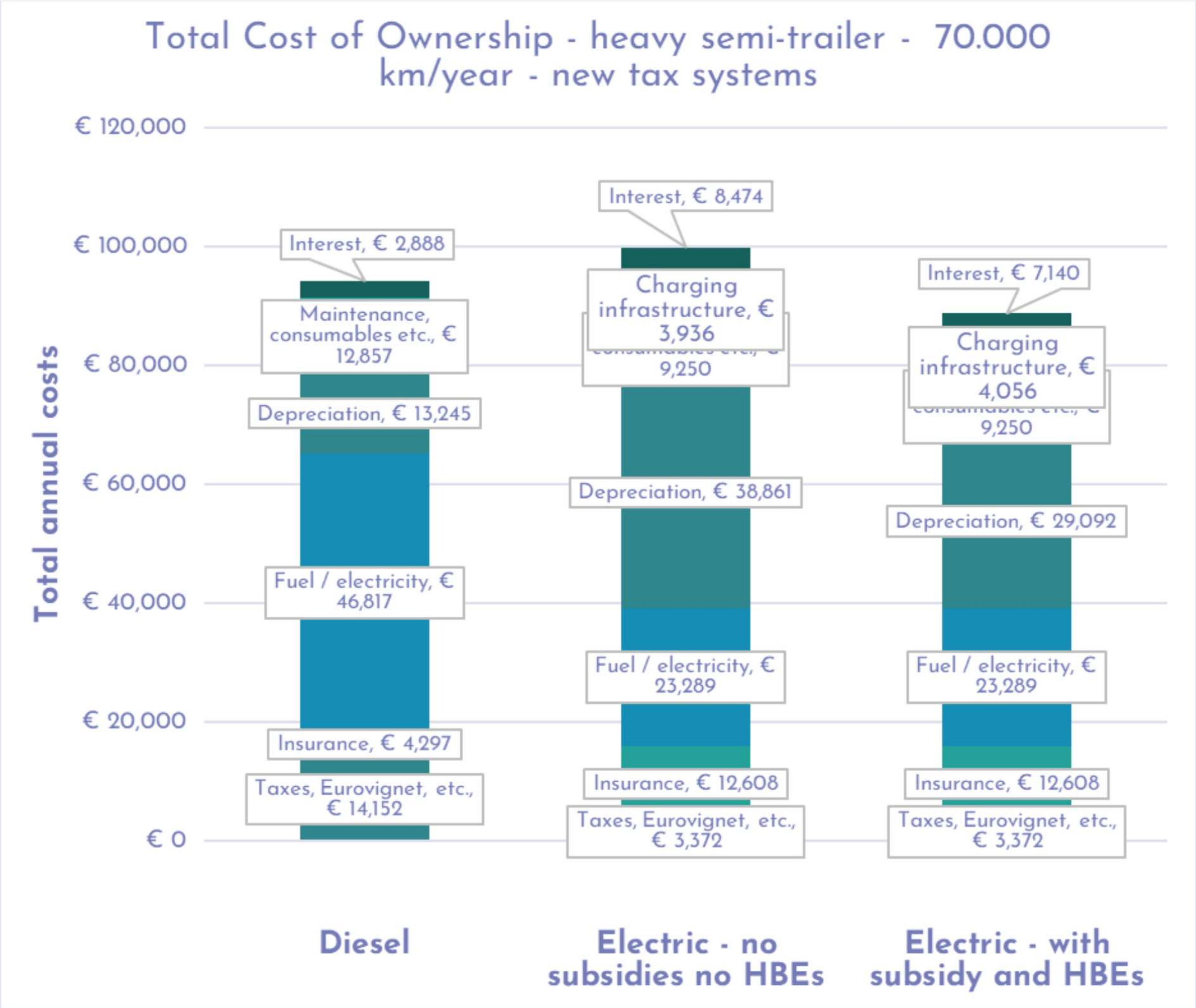

Figure 21: Total Cost of Ownership calculation Example 2 for new tax system, including breakdown of cost elements. Figures should be read as indicative. (left-to-right: diesel, electric, electric with current incentives)

It is also expected that the purchase price of e-trucks will be reduced once mass production is higher. The cost for the battery modules are a significant part of the difference between the diesel and e-truck. Cost projections as shown in Figure 22 based on [26] indicate a 40% reduction of costs per kWh in 2030 when compared to 2024. Total battery capacity on next generation e-trucks will be higher to enable more adequate daily operational range, it is here assumed half of the cost reduction –so 20%- should be feasible. When purchase price goes down, also the directly related costs for insurance and interest will be lower. When this e-truck price projection is realized, the incentives seem not needed to make for the good e-truck business case.

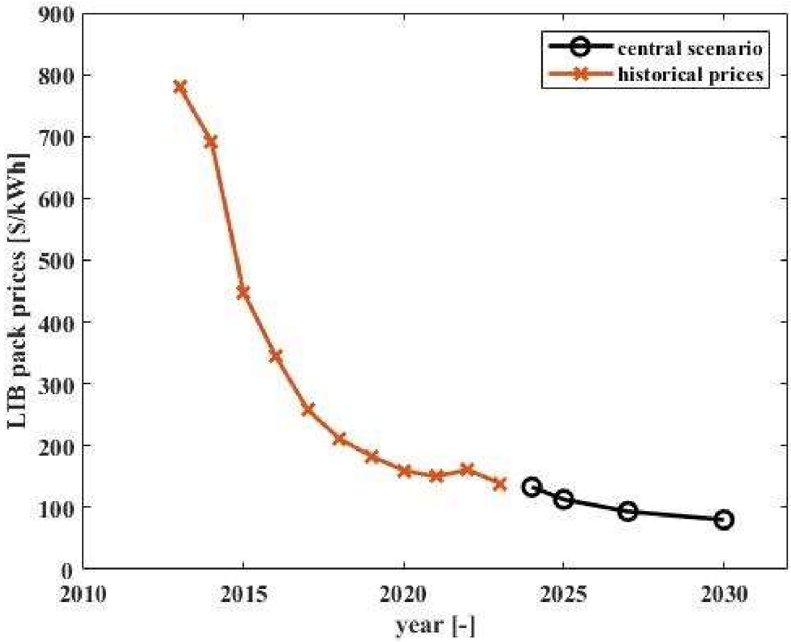

Figure 22: Historical costs development of an average lithium-ion battery (LIB) pack, including the price development expectations up to 2030 [26].

10. Conclusions

Monitoring and analysis

In the monitoring of the **10 full battery-electric heavy-duty trucks ('e-trucks')** of the MAGPIE fleet, **354 tonnes of CO_{2e}** were avoided over a total of more than **0.9 million kilometres** across the regions of the Netherlands, resulting in an operational reduction of **44%** in CO_2 emissions. These avoided emissions were based on the EU grid mix of electricity production as reported by the JRC and the Dutch Emission Registry. The other pollutants investigated in this study were NO_x and PM. For NOx, since e-trucks do not produce any tailpipe NO_x operationally, they are an obvious choice for preventing NO_x emissions. 1921 kg of NOx emissions were avoided during the demonstration period of this project by the running of e-trucks. E-trucks produced 13% less PM_{10} and 47% less $PM_{2.5}$ when compared to an equivalent Euro VI diesel truck. In the case of particle matter emissions, although the e-trucks are a lot cleaner because there are no emissions from the engine itself, the road, tyre and brake are still a large source of particle emissions. It should be noted, that participating transport companies reported faster tyre degradation for electric trucks, which could potentially increase PM emissions. Although not in the scope of this study, further research in this domain could lead to different conclusions.

In terms of the operations of e-trucks, on average, 85% of the total charged energy is used for driving and the rest for auxiliaries. Recuperation, i.e., energy recovered by braking reduced the total energy consumption by 12%. On average, the e-trucks were driven with a combination weight of **26.2 tons** out of which 18 tons is the weight of the empty truck-trailer combination. They also only drove an average of **280 kilometres per day**. This also goes on to say that the transporters treat the e-trucks as more of an experiment and have slightly less confidence in utilizing its full payload potential.

Experience with battery-electric heavy trucks in logistics operations

At this time, battery-electric heavy duty truck owners are still in an experimentation phase and mindset. This means that they are willing to take some extra steps to integrate the e-trucks into their operations, such as specially selecting work for them to do, accepting reduced profitability per trip, re-arranging operations to allow for opportunity charging, specially selecting drivers who are comfortable with electric vehicles, etc.

Total cost of ownership, ability to recharge, need for planning, and limited range are shown to be the current issues. Still, the e-truck owners are finding solutions (often ad hoc) to enable the successful usage of battery-electric vehicles in their daily operations. Barriers to scaling up the adoption of e-trucks are the limited battery capacity (for long-haul) which causes range and planning problems, grid congestion which prevents the building of more e-truck chargers in many locations, and higher cost and lack of willingness of clients to pay more for electric transportation.

TCO calculations

At this moment, battery-electric heavy-duty trucks are more expensive to buy, cheaper to operate but, all together, with a higher total cost of ownership, than diesel trucks. Subsidies can close this gap, at least in the Netherlands and under the right circumstances. The most important subsidies are the AANZET-subsidy, which lowers the purchase price of an e-truck, and the HBE trading programme where suppliers of sustainable electricity to e-trucks are paid. Without these subsidies, the TCO of an e-truck is higher than that of a diesel truck.

The purchase price of e-trucks is expected to come down. This is due to technological advances, increased competition between manufacturers, and economies of scale [27]. ETS2 and the new truck tax rules will make zero-emission trucks more competitive per km driven.

In the TCO calculation it is shown that a 10% decrease in the purchase price of the battery-electric vehicle is enough to make it cost-competitive with diesel trucks without subsidies.

All in all, it is highly likely the TCO gap between diesel trucks and battery-electric heavy-duty trucks will be closed in the coming years due to a combination of increased taxes on diesel trucks and lower purchase price of battery-electric heavy-duty trucks.

11. References

[1] various, *MAGPIE - sMArt Green Ports as Integrated Efficient multimodal hubs - project proposal for Call: LC-GD-5-1-2020,* 2021.

[2] "Dashboard Electric Vehicle," RVO, [Online]. Available: https://duurzamemobiliteit.databank.nl/mosaic/en-us/elektrisch-vervoer/zware-bedrijfsvoertuigen. [Accessed 4 9 2025].

[3] Dadikozyan, A., "Battery Diagnostics and Monitoring Methods - A Comparative Analysis of Active versus Passive Approaches-," *EVTeC 2025 - 7th International Electric Vehicle Technology Conference 2025,* 2025.

[4] Irene Zubin, et.al., "State of the art on electric heavy duty trucks and development plan for demo 9 sub-topic 1," TNO, 2022.

[5] "Media Volvo Group," [Online]. Available: https://media.volvogroup.com/dam/spaces/4b4256a675f541cda2d7f9ca8a4e85a8/items/aee99bd7665d43c08e0fb0de0072d405. [Accessed 1 9 2025].

[6] "Media Volvo Group," [Online]. Available: https://media.volvogroup.com/dam/spaces/4b4256a675f541cda2d7f9ca8a4e85a8/items/094805d7e00543f1b649b03f006e7205. [Accessed 1 9 2025].

[7] [Online]. Available: https://www.sae.org/news/2024/05/volvo-trucks-battery-chemistry.

[8] "Volvo FM Electric specification sheet," [Online]. Available: https://stpi.it.volvo.com/STPIFiles/Volvo/ModelRange/fm42te_gbr_eng.pdf. [Accessed 8 9 2025].

[9] "Volvo FH Electric specification sheet," [Online]. Available: https://stpi.it.volvo.com/STPIFiles/Volvo/ModelRange/fh42te_8ne_engvt.pdf. [Accessed 8 9 2025].

[10] E. Commission, "Type-approval of motor vehicles and engines with respect to emissions from heavy duty vehicles (Euro VI) and on access to vehicle repair and maintenance information," 18 6 2009. [Online]. Available: https://eur-lex.europa.eu/eli/reg/2009/595/oj/eng.

[11] E. Commission, "Type-approval of motor vehicles and engines and of systems, components and separate technical units intended for such vehicles, with respect to their emissions and battery durability (Euro 7)," 8 5 2024. [Online]. Available: https://eur-lex.europa.eu/eli/reg/2024/1257/oj/eng.

[12] E. Commission, "'Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutrality," 14 7 2021. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52021DC0550.

[13] E. Commission, "Strengthening the CO2 emission performance standards for new heavy-duty vehicles and integrating reporting obligations," 6 6 2024. [Online]. Available: https://eur-lex.europa.eu/eli/reg/2024/1610/oj.

[14] "Emissieegistratie.nl," [Online]. Available: https://www.emissieregistratie.nl/sites/default/files/2025-04/2025-0006%20(RIVM)%20Methodology%20report%20Transport%20ER%201990-2023.xlsx. [Accessed 14 09 2025].

[15] "TCO - Vracht," Panteia, [Online]. Available: https://topsectorlogistiek.nan.works/tco-vracht. [Accessed 18 08 2025].

[16] "CO2 emissiefactoren.nl," [Online]. Available: https://co2emissiefactoren.nl/. [Accessed 14 9 2025].

[17] "Energy Policy Review The Netherlands 2024," International Energy Agency, 2024.

[18] U.S. Environmental Protection Agency, "U.S. EPA. Integrated Science Assessment (ISA) For Oxides of Nitrogen – Health Criteria," Washington, DC, 2016.

[19] Netherlands Enterprise Agency (RVO), "Purchase subsidy zero emission trucks AanZET," [Online]. Available: https://business.gov.nl/subsidy/purchase-subsidy-zero-emission-trucks-aanzet/. [Accessed 01 September 2025].

[20] Netherlands Enterprise Agency (RVO), "Subsidy for private charging stations (SPRILA)," [Online]. Available: https://business.gov.nl/subsidy/sprila/. [Accessed 01 September 2025].

[21] Rijksdienst voor Ondernemend Nederland (RVO), "Hernieuwbare energie voor vervoer," [Online]. Available: https://www.rvo.nl/onderwerpen/bio-energie/hernieuwbare-energie-vervoer. [Accessed 01 September 2025].

[22] Rijksdienst voor Ondernemend Nederland, "Belastingvoordeel met MIA en Vamil," [Online]. Available: https://ondernemersplein.overheid.nl/mia-vamil/#art:wat-is-miavamil. [Accessed 08 08 2025].

[23] "Vrachtwagenheffingsbeleid: Verwachte tarieven," Rijksoverheid, [Online]. Available: https://www.vrachtwagenheffingsbeleid.nl/programma/tarieven. [Accessed 08 08 2025].

[24] CE Delft, "Hoe blijft de gasrekening betaalbaar - policy paper," 2024.

[25] Rijksoverheid, "https://www.vrachtwagenheffing.nl/dit-gaat-u-betalen," [Online]. [Accessed 08 08 2025].

[26] BloombergNEF, "Lithium-Ion Battery Pack Prices Hit Record Low of $139/kWh," 2023.

[27] "Europe's market for e-trucks set to accelerate in 2025," ING, 2025. [Online]. Available: https://think.ing.com/articles/europes-market-for-e-trucks-set-to-accelerate-in-2025/. [Accessed 08 08 2025].

[28] R. B. C. C. B. &. M. C. Sacchi, "When, where and how can the electrification of passenger cars reduce greenhouse gas emissions?.," *Renewable and Sustainable Energy Reviews,* vol. 112475, p. 162, 2022.

[29] G. K. E. K. A. &. H. R. Booto, "Comparative life cycle assessment of heavy-duty drivetrains: A Norwegian study case.," *Transportation Research Part D: Transport and Environment,* vol. 102836, p. 95, 2021.

[30] L. S. V. S. K. P. S. W. V. &. S. T. Peiseler, "Carbon footprint distributions of lithium-ion batteries and their materials," *Nature Communications,* vol. 15, no. 10301, p. 1, 2024.

[31] N. A. S. M.-P. S. e. a. Hill, "Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA – Final report," *Publications Office of the European Union,* 2020.

[32] M. &. B. G. NEGRI, "Life-cycle greenhouse gas emissions from passenger cars in the European Union.," *ICCT.*

[33] C. S. B. H. M. H. C. v. d. M. M. &. T. A. Xu, "Future greenhouse gas emissions of automotive lithium-ion battery cell production," *Resources, Conservation and Recycling,,* vol. 106606, p. 187, 2022.

[34] Netherlands Enterprise Agency (RVO), "Purchase subsidy zero emission trucks AanZET," Business.gov.nl, [Online]. Available: https://business.gov.nl/subsidy/purchase-subsidy-zero-emission-trucks-aanzet/. [Accessed 21 September 2025].