Safety of electric driving – logistics and construction

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CONTENTS

SUMMARY

In November 2020, CE Delft published the Safety and Electric Passenger Cars study [1], commissioned by the NAL[1] Safety working group, containing a detailed overview of all safety aspects related to charging and driving electric passenger cars. However, the use of battery-powered electric vehicles and mobile machinery in the logistics sector and on construction sites was not included in this overview. In order to better understand the risks and regulations regarding the various safety aspects in these sectors too, the NAL Safety working group and the DNV Logistics working group jointly commissioned a study into battery-powered electric vehicles and mobile machinery in the logistics and construction sectors. Electric buses are addressed in a separate study by CE Delft [2] and, therefore, fall outside the scope of this report. The following **research questions** form the basis of this study (relating to battery-powered electric vehicles and mobile machinery in logistics and construction):

1. Are there any relevant research results, obtained either in the Netherlands or abroad?
2. What are the general and safety-specific laws and regulations, standards, safety requirements and quality standards? Are these regulations complied with? Are they enforced?
3. What are the risks for the various safety aspects, are there any knowledge gaps and are current regulations enough?

Literature, other public sources and DNV's own knowledge and information were used to answer these research questions. Interviews were then held with several parties from both sectors, drawing on initial insights and open-ended questions. Once the information obtained from all sources had been analysed, a report was drawn up; feedback from the project's supervisory group and their stakeholders was incorporated in several rounds of revisions.

This study broadly suggests that the safety risks (probability times impact) associated with battery-powered electric vehicles and mobile machinery in logistics and construction are, for now, limited, in both absolute and relative terms compared to conventional vehicles and mobile machinery. Although some incidents may have a major impact, especially if mitigation is inadequate, the likelihood of this happening is limited, and due to the current small numbers of vehicles, incidents will still be rare. However, it is recommended that efforts be made now to address the most serious safety risks identified, in view of the expected substantial growth of battery-powered electric vehicles and mobile machinery in logistics and construction in the years to come; this growth will ultimately lead to these risks materialising. It is also prudent to monitor this growth and the development of (numbers of) incidents and safety risks so that, where necessary, adjustments can be made in good time.

The two tables below summarise the **risks** and most significant **knowledge gaps** for logistics and construction respectively. The risks are subdivided according to their risk assessment.[2]

[1] Dutch National Agenda for Charging Infrastructure (*Nationale Agenda Laadinfrastructuur*)

[2] This is a qualitative assessment (probability times impact) for the risks identified per topic. Levels used: low, medium and high. High risk refers to the expectation that the risks involved will lead to low-impact incidents within months, and/or to high-impact incidents within a few years.

Risks and knowledge gaps regarding EVs in **logistics**	
High risk	- *Incident management:* Knowledge sharing is limited due to the reluctance of manufacturers and a fragmented regional approach. The variety of vehicle brands and types impedes the acquisition of knowledge. Information about trucks recorded in the information systems used by emergency services is incomplete. No solution for securing burnt e-trucks. - *Behaviour and processes:* little knowledge and experience with EV safety. NEN 9140 not properly implemented everywhere.
Medium risk	- *Vehicle safety:* inspections of retrofitted vehicles may be insufficient. - *Fire safety*: in the event of a fire, possible spreading to nearby vehicles and possible impact on nearby structures. - *Enclosed spaces:* fire safety requirements not specific to EVs; possibly insufficient fire extinguishing water available.
Low risk	- *Visible and invisible battery damage:* safety of battery ambiguous after an incident. - *Incident management:* procedure that is to be followed in the event an EV ends up in (a body of) water is not suitable for e-trucks - *Charging infrastructure:* regular safety inspections and maintenance not mandatory. Risk of collision with charging infrastructure. Risk of overloading in certain cases. - *Noise and the absence thereof:* increased traffic risk for EVs without AVAS. - *Behaviour and processes:* risk of exceeding the load weight due to extra weight of battery.
Main knowledge gaps	- Determination of fire behaviour depends on vehicle type and location of batteries. - Determination of the impact of (intense) EV fires on the structural safety of nearby structures. - Alternative methods of extinguishing and salvaging e-trucks, especially in enclosed spaces.

Risks and knowledge gaps regarding electric mobile machinery in **construction**	
High risk	- *Incident management:* no solution for securing burnt electric mobile machinery and equipment. Incomplete information about electric mobile machinery in systems used by the emergency services. - *Behaviour and processes:* little knowledge and experience with safety, increased risk due to solution-oriented mindset and generally limited electrical engineering expertise; limited knowledge sharing.
Medium risk	- *Vehicle safety:* inspections of retrofitted electric mobile machinery may be inadequate; drivers, etc., may be insufficiently familiar with the different specifications of electric mobile machinery. - *Visible and invisible battery damage:* higher risk of (mechanical) incidents in construction, after which battery safety is unknown, especially when additional batteries are fitted. - *Fire safety*: in the event of a fire, possible spreading to nearby electric mobile machinery and possible impact on nearby structures. Lack of knowledge can lead to unsafe practices. - *Charging infrastructure:* use of unsafe charging infrastructure (e.g., at locations without electricity).
Low risk	- *Noise and the absence thereof:* potentially increased traffic risk due to lack of noise caused by electric mobile machinery and vehicles without AVAS, possibly also safety benefits.
Main knowledge gaps	- Alternative extinguishing and salvaging methods on construction sites. - Risks of electric mobile machinery in ATEX environment and related solutions. - Test protocol / validation requirements for each type of retrofitted electric mobile machine. - Determining whether battery pack is damaged after an incident. - Determination of fire behaviour depending on the type of electric mobile machine and location of the battery. - Determination of the impact of (intense) fires on the structural safety of nearby structures.

In light of the abovementioned risks and knowledge gaps, 17 **recommendations** have been formulated in the following categories: battery, vehicle safety and incident management, behaviour and processes, noise and charging infrastructure. Four of these recommendations have been prioritised and are presented below:

- Pay extra attention to the inspection of the battery pack in electric vehicles and mobile machinery that have been retrofitted or have mounted elements. The inspection agency will have to check that the required design requirements have been followed and that tests and validations have been carried out sufficiently and correctly.
- Develop methods for the long-term securing of burnt large EVs, for example: requirements for fire propagation, new extinguishing methods, new protocols for securing (large) EVs.
- Improve the accumulation of knowledge by implementing uniform protocols, a national approach/training and sharing knowledge of incidents and near misses within the sector.
- More comprehensive training for employees in both logistics and construction regarding EVs and electric mobile machinery and their batteries: handling, recognising risks, what to do in the event of an incident. Topics include collisions, falling of loads, handling (exchangeable) batteries, preventing and dealing with damage to batteries, etc. Relevant work regulations must be revised.

1 INTRODUCTION

1.1 Background

Electric vehicles are becoming increasingly popular in the Netherlands and abroad. Compared to petrol and diesel vehicles, however, electric vehicles and mobile machinery are still relatively new and uncharted territory. One of the main issues for the government, among others, is the safety risks associated with the introduction of a new technology such as electric vehicles. In November 2020, CE Delft published the Safety and Electric Passenger Cars study [1], commissioned by the NAL[3] Safety working group, containing a detailed overview of all safety aspects related to charging and driving electric passenger cars. However, the use of electric vehicles and mobile machinery in the logistics sector and on construction sites was not included in this overview. In order to better understand the risks and regulations regarding the various safety aspects in these sectors too, the NAL Safety working group and the DNV Logistics working group jointly commissioned a study that focusses solely on battery-powered electric vehicles and mobile machinery in the logistics and construction sectors. Electric buses are addressed in a separate study by CE Delft [2] and, therefore, fall outside the scope of this report.

The following research questions form the basis of this study (relating to battery-powered electric vehicles and mobile machinery in logistics and construction):

1. Are there any relevant research results, obtained either in the Netherlands or abroad, regarding safety and charging and driving electric vehicles in logistics and construction?
2. Which laws and regulations, standards, safety requirements and quality standards apply in the field of electric transport and safety? Are these regulations complied with? Are they enforced?
3. What are the risks for the various safety aspects, are there any knowledge gaps and are current regulations enough?

1.2 Approach used for this study

1.2.1 Steps taken

The first step of this study consisted of a literature review. In order to answer the research questions, we looked for and used specialist and scientific literature, other public information sources such as websites, news reports, knowledge and experience of DNV experts, information from DNV (e.g., from previous studies, calculations and tests) and new analyses. We then conducted interviews with various parties (see the following subsections), drawing on initial insights and open-ended questions. Once we had analysed the information obtained from all sources, we compiled a draft report, which we then presented to the members of the project's supervisory group and the NAL Logistics working group, in which both the logistics and construction sectors are represented in various task forces. We then incorporated their feedback and that of their stakeholders, if applicable, into the definitive report. The composition of the supervisory group can be found in Appendix B.

1.2.2 Interviews

Interviews with various stakeholders from the logistics and construction sectors, as well as industry associations, were used as additional sources. Getting input from parties active in the sectors concerned, especially with regard to which EVs are used, in which situations, and existing knowledge about risks, safety measures and incidents, is particularly beneficial (e.g., additional points, nuances, details).

In consultation with various interviewees, the content of the interviews is not presented verbatim in this public report. In many interviews, potentially sensitive information was touched upon from time to time, such as commercially sensitive insights, plans and contexts that are not (yet) public, or personal opinions that may deviate from the official position of

[3] Dutch National Agenda for Charging Infrastructure (*Nationale Agenda Laadinfrastructuur*)

the interviewee's organisation. The organisations in question did not consent to the verbatim reproduction of all information discussed, which, given the purpose of the interviews, does not present a problem for this study. Instead, we conducted an extensive analysis of all the information obtained from all the interviews, which resulted in a comprehensive overview of insights and trends that were taken into account when answering the research questions.

A list of parties to be interviewed was compiled in consultation with the supervisory group; all parties were interviewed. The final list of parties and individuals who were approached and interviewed can be found in Appendix B.

1.3 Structure of this document

In the opening chapter, we start by explaining why and how this study was conducted. We also discuss a number of key developments and backgrounds that are useful for putting the results of the study into context. In chapter 2, we examine the results of this study in detail, focusing in particular on electric transport and charging in the logistics sector. Here, we explain which vehicles fall under this category, before reviewing existing research, laws and regulations, standards, safety requirements and risks per safety category. The safety categories are taken from the RVO research questions, with an 'Other' category added. In chapter 3, we present the research results for the construction sector using the same format. We present our conclusions and recommendations, including risks and knowledge gaps, in chapter 4. We have included references, a list of abbreviations and appendices at the end of the report.

1.4 Background and developments

To contextualise and better understand the insights and conclusions of this study, in this section we provide relevant background information and discuss related developments.

1.4.1 Motives for switching to electric vehicles – logistics sector

Zero emissions for urban distribution

The National Climate Agreement states that, by 1 January 2025, at least 30 to 40 municipalities will have introduced a zero-emission zone. After that date, all new trucks and vans that want to enter a zero-emission zone must be emission-free; from 2030 onwards, all vehicles wanting to enter these zones must be emission-free. To date, 26 municipalities have decided to introduce a zero-emission zone for urban logistics [3].

As a result, initial experiences are being gathered in densely populated areas [4]. There is also some anxiety in the market as to whether sufficient charging infrastructure can be provided. There are major challenges facing charging infrastructure, especially in terms of obtaining sufficient connection capacity to the power grid. Consequently, parties are cooperating within the framework of the National Agenda for Charging Infrastructure to ensure that sufficient charging infrastructure is available for logistics.

1.4.2 Motives for switching to electric vehicles and mobile machinery – construction sector

Emission-free construction

Sustainability is also becoming increasingly important in the construction sector, for now still primarily driven by the wishes of government bodies such as the national government, municipalities, water boards and the Rijkswaterstaat. The National Climate Agreement, the Clean Air Agreement and the Approach to Nitrogen, among others, have expressed the ambition to clean up mobile machinery and vehicles used in the construction industry and to make them emission-free. The roadmap for Clean and Emission-free Construction (SEB, *Schoon en Emissieloos Bouwen*) aims to achieve a 60% reduction in nitrogen, a 75% improvement in health and 0.4-megaton reduction in CO2 in construction by 2030 [5].

Diesel-powered mobile machinery emits a significant amount of emissions. The use of electric mobile equipment helps the construction industry to reduce emissions of CO2, nitrogen and particulate matter on the construction site. Electric mobile machinery is also quieter to operate, which means that it generates less noise nuisance for both workers and the surrounding area. Furthermore, electric mobile machinery is easier to maintain. The costs associated with maintenance and power are lower than for fossil-fuel-powered machines. BMWT[4] has noticed that the range of products on offer is expanding [6], especially in response to demand from projects being implemented in quiet areas and/or urban areas.

BasicInspectionModule (BIM) Exposure to Diesel Engine Emissions (DEE)
Last year, the BIM Exposure to Diesel Engine Emissions was updated to reflect the latest technological developments. On 1 July 2020, the statutory limit value for DEE came into force [7], which is applicable to work activities and workplaces where people are exposed to DEE. This BIM is a key driving force behind the electrification of the construction industry.

1.4.3 Differences with electric passenger vehicles and buses

The following sub-sections provide a general overview of the differences between electric vehicles and mobile machinery in construction and logistics compared to passenger electric vehicles and conventional vehicles or machinery in the sectors respectively. Clarifying differences and similarities, as well as the areas in which they occur, can make it easier to identify and understand potential safety risks.

Design

- In terms of their design, electric models of logistics vehicles and mobile machinery are very similar to ICE[5] models. The main difference is the drive, which is powered by an electric motor and battery. The same differences in terms of the centre of gravity, mass and drive that have been identified for electric passenger vehicles also apply to these vehicles and machines.

Location

- Logistics: in addition to driving on public roads, they are also used near warehouses, shops and on industrial estates. Battery charging sometimes takes place during loading/unloading.
- Construction: irregular terrain, sand and dust; limited on-site charging infrastructure.

Energy capacity

- The energy capacity of batteries for electric trucks can vary between 100 kWh and 600 kWh depending on the type of vehicle (this is similar to e-buses), while current passenger EVs can reach up to 120 kWh. The voltage is not higher than for a passenger EV; this is typically between 400 volts and 800 volts DC.

Location of the battery pack

- The battery pack in passenger electric vehicles is usually located along the bottom of the chassis, but in electric trucks and mobile machinery there are several options, for example in the central lower area or at the side. Delivery vans are similar to passenger electric vehicles.

Trucks versus buses

- Location of batteries in the vehicle: in e-buses, sometimes on top and sometimes at the bottom; in e-trucks, usually in the central lower area or at the side.
- Public transport buses drive a regular route with designated charging points; trucks have access to charging points on the company's own premises and may require rapid charging en route. In this sense, e-trucks are similar to electric coaches.
- Loading/unloading in the city at locations with many pedestrians and cyclists; this is similar to a bus stop.

[4] BMWT is the branch organisation of suppliers of construction machinery, warehouse installations, road construction machinery and transport equipment.
[5] Internal Combustion Engine

- The body of an e-truck may also contain an electrical system with many consumers (electrical devices), for which one or more additional batteries are used.

1.4.4 Differences from conventional vehicles and mobile machinery in logistics and construction

The summary below excludes battery-powered construction equipment (non-mobile).

Drivetrain

- Electric motor instead of combustion engine (by definition)
- Less maintenance
- High electrical voltage poses an additional risk
- Fire safety and incident management are different

Battery pack

- Battery at the bottom: lower centre of gravity
- Battery is sometimes located in an unusual place
- Mass: greater mass and therefore more inertia
- More design freedom: e.g., battery packs located at the front and rear
- Increased acceleration: higher level of alertness required in enclosed spaces
- Braking: recovering energy means faster and harder braking

Charging infrastructure

- Instead of petrol stations, charging stations are required at central locations, along transport corridors or on industrial estates or construction sites / construction hubs.
- Additional need for grid capacity on the construction site, which is not always available. Can potentially be overcome by using mobile charging infrastructure in combination with an energy storage system.
- Swapping batteries (replacing empty batteries with full ones) is a possible alternative to local charging on the construction site.

Bodywork

- Some types of trucks are more difficult to electrify due to the high level of power required (e.g., trucks equipped with work equipment). For these types of vehicles, a hydrogen-electric alternative (FCEV) may be a solution.
- In some cases, an e-truck has two separate electrical systems – one for powering the truck itself and one for the mounted elements – each with its own battery. Truck OEMs are sometimes unwilling to make the truck battery available to the bodybuilder, for example because it would limit the range of the truck. This results in there being two connection points for charging. Generally speaking, there is room for improvement regarding the cooperation between truck suppliers and bodybuilders. These kinds of issues are teething problems in an emerging sector.

Loading weight

- The weight of the unladen vehicle can be distributed differently and also be higher due to the battery, but the maximum weight must remain the same for each vehicle class.[6] The result is that an EV can carry slightly less payload.

1.5 Status of electrification in logistics and construction

The logistics and construction sectors are not immune to the broader trend of electrification. A small proportion of vehicles and mobile machinery in logistics and construction are already electrified [8], and this figure is expected to rise rapidly. At present, this mainly concerns pilot and demonstration projects designed to gain practical experience. The current fleet of electric vehicles and mobile machinery primarily consists of retrofitted models, although some OEM models for logistics and construction are now being sold on the market.

The electrification of delivery vehicles (cat. N1) is in line with developments in the passenger EV market. These are already available as standard from OEMs, and many distribution companies are keen to electrify a substantial proportion of their fleets in the coming years.

The electrification of trucks (cat. N2/N3) is lagging behind that of passenger cars (partly due to scale) and buses (partly due to bus routes being easier to plan: often a smaller operating range, regular routes and easier to schedule recharging). The expectation is that a range of light- and heavy-duty e-trucks will be commercially available by around 2025 [9].

The electrification of mobile machinery in the construction industry is very much in the pilot phase. Since these are often specialist machines that are manufactured in limited numbers, they are not yet commercially viable for suppliers. In the construction sector, the electrification process is progressing from small to large machinery (starting with small excavators and the like), whereby ‘large’ machinery is still uncommon at the moment, but the market is developing rapidly.

At the moment, demand for electric vehicles and mobile machinery from, for example, municipalities is greater than the volume supplied by OEMs, which has yet to take off. Consequently, retrofits are currently being used; in this instance, a standard ICE vehicle or mobile machine is converted to a battery-powered model (drivetrain electrification) by a third party. It is anticipated that retrofitting will continue to play a significant role in the market until 2030, especially for heavier trucks and construction machinery. The retrofit industry is extremely diverse and sometimes lacks expertise, which could lead to increased safety risks.

[6] For electric delivery vans, the maximum weight (for a Category B driving licence) has been increased from 3,500 kg to 4,250 kg.

2 LOGISTICS

This chapter presents an overview of the safety aspects related to electric transport vehicles in the logistics sector.

2.1 Scope

The logistics transport discussed in this chapter concerns all transport on public roads.[7] This means that these vehicles must have number plates and require type approval by the RDW (Netherlands Vehicle Authority). The RDW differentiates between the categories N1 to N3. This classification is based on the European classification, whereby the N category applies to logistics vehicles and the M category to passenger vehicles [10].

Table 2-1 Classification of logistics vehicles with charging capacities and numbers in circulation [11], [12].

Cat.	Type	Weight (tonnes)	Average charging capacity (kW)	Average battery pack (kWh)	Numbers in circulation* (NL)
N1	Delivery vans	<= 3.5 (ICE); <= 4.25 (EV) (see 2.1.1)	Standard: 7-22 (AC) Rapid: 150-350 (DC/HPC)	40-100	852,000
N2	Light-duty trucks	3.5-12	Standard: 50-150 (DC/HPC) Rapid: 150-350 (DC/HPC)	100-250	62,000
N3	Heavy-duty trucks	>12	50-350 (DC) *Potentially heading towards 1-4 MW*	125-600	74,000

* This is the total number (fuel-powered cars and EVs), of which the proportion of EVs is still very limited.

In late 2020, ElaadNL published a forecast [9] for the proportion of logistics e-vehicles in the Netherlands. The projection for 2035 is as follows: delivery vehicles - 61%, e-trucks for urban logistics - 84% and e-trucks for national and international transport - 42%.

Light electric vehicles (LEVs) such as electric mopeds, bikes and delivery bikes fall outside the scope of this study.

2.1.1 N1 – Delivery vans (up to 3.5 tonnes)

N1-category vehicles are used in urban environments for delivery and distribution, catering, construction and service maintenance, among other things. Electric models of this type of van are commercially available from well-known car manufacturers (OEMs) such as Daimler and Nissan. Electric delivery vans are exempt from the requirement to have a Category C driving licence for driving an electric delivery van with a *gross vehicle weight* (GVW) of up to 4,250 kg [13]. This means that, with this exemption, a Category B driving licence is sufficient.

Battery packs and outputs, and therefore also the use of charging infrastructure, are comparable to passenger electric vehicles.

[7] Electric vehicles used in intralogistics, such as electric forklift trucks, are not included in this report therefore. Nevertheless, some insights and conclusions from this study may be relevant for these vehicles.

Figure 2-1   Examples of N1 category electric vehicles. Source: Albert Heijn (left), Nissan (right).

2.1.2 N2 – Box truck, lorry (up to 12 tonnes)

N2 category vehicles are mainly used for urban logistics such as catering and moving services. The process of electrifying these vehicles is in its infancy. At present, these tend to be retrofitted vehicles, where the standard ICE model has been fitted with an electric motor and battery by a third party (e.g., E-moss). The first OEM vehicles are now available on the market and are already in circulation. Each retrofitted vehicle must be individually tested and approved by the RDW.

The battery packs (kWh) and outputs (kW) in this category are typically larger than those of passenger EVs. Depending on the charging scenario and the size of the vehicle, charging takes place via AC or DC charging infrastructure.

Figure 2-2   Examples of N2 category electric vehicles. Source: Logistiek010.

2.1.3 N3 – heavy-duty transport – tractive unit with semi-trailer (from 12 tonnes)

N3 category vehicles are mainly used for construction logistics, provisioning and waste collection services. Like the N2 category, the electrification of this type of vehicle is still in its infancy. The majority of electric vehicles currently on the road are retrofits. The weight in this category ranges between 12 and 60 tonnes on average. One of the most recent heavy-duty EVs is a retrofitted 50-tonne crane truck. The first OEM vehicles in this category are also commercially available.

Figure 2-3 Examples of N3 category electric vehicles. Source: Vlot Logistics (left), Volvo (right).

The battery packs and outputs in this category are significantly larger than those of passenger EVs. Depending on the charging scenario, this type of vehicle will mainly be charged using DC charging infrastructure with capacities between 50 and 350 kW. A global standard is under development [14] for achieving higher charging capacities between 1 and 4.5 MW. These outputs will be especially useful for inter-urban and rural freight traffic over longer distances, where vehicles need to be recharged quickly en route. ElaadNL expects the first of these charging facilities to be operational between 2025 and 2030 [9].

The battery pack is usually fitted behind the cabin, on one or both sides of the vehicle. The unladen mass of an N3 category electric vehicle has the potential to be up to 2,500 kg heavier than a standard ICE model [15], primarily due to the weight of the batteries. This can lead to a slightly longer braking distance (in unladen condition). Electric vehicles accelerate faster than standard ICE models. The electric drive system also makes them easier to drive (automated transmission), with rapid acceleration and easy handling without vibration and noise. According to the category requirements, a loaded EV may not be heavier than a loaded ICE vehicle.

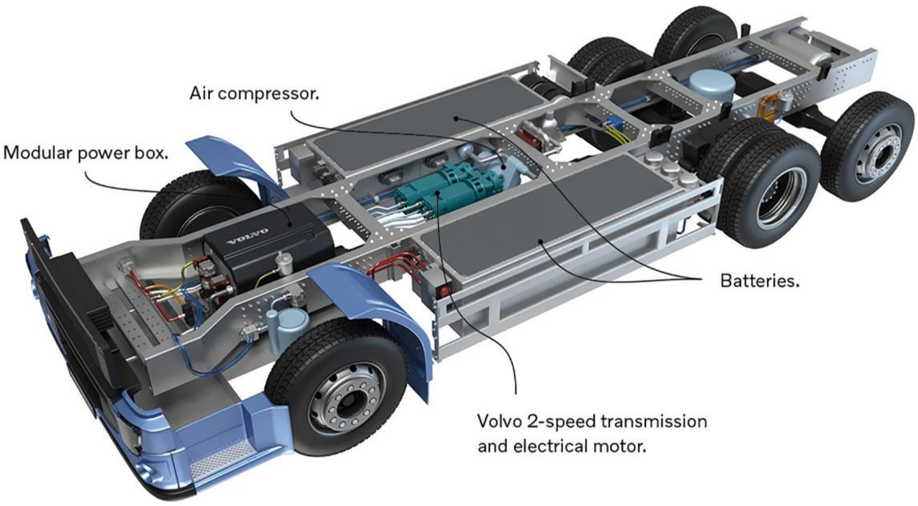

Figure 2-4 Example of the undercarriage of an electric truck with the battery packs on both sides. Source: Volvo.

2.2 Vehicle safety

In terms of electrification, vehicle safety primarily concerns the mass, the centre of gravity, acceleration and the braking distance of the vehicle, which may be different compared to an ICE vehicle. Like passenger electric vehicles, logistics vehicles are equipped with advanced systems such as a battery management system (BMS) and an emergency braking system (AEBS). Autonomous driving is also in development; for example, autonomous trucks are being developed that are able to drive in a convoy on the motorway ('truck platooning') [16].

2.2.1 Existing research

There is currently a limited amount of publicly available literature that focuses specifically on the safety of logistics EVs. In 2016, the Institute for Safety (IFV - *Instituut Fysieke Veiligheid*) commissioned a study on the fire safety of electric buses. [17] The report on zero-emission buses published by CE Delft [2] also addresses vehicle safety. In this section, we draw parallels with e-trucks from this report.

Additionally, reports by truck manufacturers (OEMs) such as Volvo and Scania show that vehicle safety of e-trucks (cat. N2/N3) is still undergoing further development (e.g., collision and road tests) [18].

2.2.2 Laws and regulations, standards and safety requirements

Electric-powered vehicles in the logistics sector are, just like electric-powered passenger vehicles, subject to the 1994 Road Traffic Act (*Wegenverkeerswet*), which requires safety tests, among other things. Before a vehicle is allowed on the road, a type approval from the RDW is required. This tests both the car and the production process on a series of points (e.g., crash tests, an incline test, power and EM radiation tests) in accordance with European legislation on inspection requirements for vehicle safety, ECE R100 [19], which applies to both passenger vehicles (cat. M) and logistics vehicles (cat. N).

The latest version of ECE R100 (which was introduced in 2016) sets safety requirements for the battery pack in the EV. This must be successfully tested on a range of points such as mechanical shock and vibrations, temperature variations, fire resistance and short circuiting. The umbrella organisation for Electric Vehicle Safety (EVS-GTR) is currently working on a new version of the ECE R100 with adapted and additional tests regarding fire safety, immersion in water and harmful gases, among other things.

These types of tests are not carried out by the RDW, but by the battery manufacturer or car manufacturer themselves. The RDW can, however, witness the tests being carried out on site at the manufacturer's premises or elsewhere. The RDW issues test reports and certificates and also accepts test reports issued by other approved technical services and certificates issued by other approval bodies.

Retrofitted e-trucks are subject to a one-off Dutch approval through the RDW, which is compulsory for driving on public roads. The RDW then subjects the vehicle to a number of tests, including radiation tests, an incline test and a power test. An individual inspection applies to one vehicle and is only valid for registration in the Netherlands. In consultation with the RDW, a retrofitted e-truck can, under certain conditions, be issued with a permanent EU approval certificate. If a vehicle is exactly the same, it will fall under the same approval, but each vehicle will still be checked on site by the RDW. In these scenarios, too, the RDW does not test the batteries, but rather assesses the certificates and test reports issued by the manufacturer and/or supplier.

In addition to the European standards, there is a series of international standards and guidelines for the safety of electric transport [20], [21], which, for the moment, are not specifically aimed at logistics transport. The IEC is currently drafting additional standards – which are expected to be published between the end of 2021 and 2024 – that will also encompass e-trucks [22] . In the Netherlands, this falls under NEC 69, of which a host of Dutch companies active in e-mobility and charging infrastructure are members. Related standards concern in particular installation and functional requirements for charging infrastructure [23], [20] and safe working (NEN 9140) [24].

For the body on trucks, the bodybuilder must obtain permission from the relevant OEM. Furthermore, the OEM must provide sufficient information about the vehicle to ensure that the body can be fitted safely onto the vehicle.

2.2.3 Risks

Newsletters published by OEMs report that they are in the process of testing their EVs, for example with regard to crashworthiness and battery safety (see, for example, [18]). Additionally, there are several European independent test centres that test battery packs in accordance with the European requirements. If, like passenger EVs, OEM logistics vehicles have been successfully tested and approved according to the applicable European requirements, there is generally no reason to assume that these vehicles pose an additional risk on public roads compared to ICE vehicles. The current rules and the new developments regarding ECE R100 indicate that, with regard to key EV-specific design requirements such as fire safety, ongoing improvements are being made to further reduce potential risks.

In the case of retrofitting, retrofitted vehicles have not already been tested as such by the OEM during the design phase. The RDW issues a one-off approval based on road tests that also apply to ICE vehicles and additional test certifications (by third parties) specifically for the battery pack and the electric drivetrain. There is a potential risk that the test documents for the battery do not provide sufficient assurance for EV applications, e.g., because the scope of the requested tests does not fully cover all safety risks.

2.3 Visible and invisible battery damage

The main concern with Li-ion batteries is the risk of thermal runaway. This is an internal process whereby increased temperature or current in battery cells can cause a fire, releasing toxic gases. The risk of thermal runaway increases if the battery or cells are damaged, e.g., through mechanical damage, temporary overheating or a short circuit. This damage may be invisible on the outside. Therefore, it is crucial to prevent the battery from becoming damaged and to be able to detect any damage that does occur.

Unlike stationary or industrial battery systems, the design of car battery casings is much more geared towards providing mechanical protection against adverse conditions while the vehicle is in motion. As such, car batteries are very well enclosed and the risk of damage caused by things like impacts, objects/stones, or scraping over a speed bump is minimal. OEMs devote a lot of attention to the high quality of cells and battery packs (extensively tested technology from renowned brands), the battery management system (BMS) and the integration of the battery pack in the EV. Liquid-based cooling for EV batteries is also increasingly being used: this is not only beneficial for the service life, but also for safety [25].

The abovementioned points apply to all EVs: passenger EVs, e-buses and e-trucks. OEMs are focusing their efforts on passenger EVs in particular, but the same battery quality (including premium-brand cells, maximum BMS control and robust installation) will also be used for buses and trucks (it may even be possible to use two battery packs from a passenger EV design in an e-truck). As such, no additional problems are anticipated with regard to batteries for electric trucks. Given the weight of the vehicle, additional battery protection, such as a thicker casing, can be added if necessary, without affecting the weight distribution of the vehicle.

As with passenger EVs, e-truck batteries must conform to rigorous automotive standards, such as those laid down in Advanced Product Quality Planning (APQP) by the Automotive Industry Action Group (AIAG) [26], the IATF 16949:2016 standard – Quality Management System for the Automotive Industry [27] and quality agreements between OEMs and their suppliers. These are requirements for crashworthiness, shock and vibrations, electrical safety and demonstrable safety of the control systems (such as the BMS). According to some of those interviewed, retrofits are not always subject to the same standards (because the minimum requirements do not go as far as these APQP standards). Therefore, the inspection should be (more) stringent in this regard, for example, including at least a visual inspection of the battery mounting and cabling and a review of the functional description of the BMS functions and the cooling system.

The BMS has sensors for determining the state of the battery, which primarily concerns its operational charge status, but also its safety condition. For example, abnormal cell voltages or temperatures in the battery pack can indicate invisible damage. Likewise, shock or vibration sensors in the battery can provide information about potential abnormal conditions. These solutions are already being used in passenger EVs and will be similar for e-trucks.

2.3.1 Existing research

The EV study conducted by CE Delft [1] addresses battery damage, particularly in relation to vehicle collisions (see also 2.2). This study also reports that the BMS can monitor the safety condition of the battery. However, this expertise primarily lies with the OEMs and is not publicly available. DNV has not found any additional studies that apply specifically to e-trucks.

2.3.2 Laws and regulations, standards and safety requirements

Battery safety, including the prevention of damage, features prominently in the European Green Deal. This issue is also addressed in the Green Deal: Sustainable Batteries [28]: 'Batteries placed on the EU market should become sustainable, high-performing and safe all along their entire life cycle.' The proposed new Batteries Regulation [29] is consistent with this objective.

The CE Delft report identifies a number of standards relating to the safety of EVs and EV batteries. As yet, no updates have been published. The standards contain few requirements for the BMS, except that it must guarantee safety. There is room for improvement here; for example, they could stipulate that the BMS must compile and maintain a 'damage report' on the battery.

The abovementioned regulations and standards are not directed specifically at e-trucks but apply to EVs in general.

CE Delft also points to PGS 37 (*Publicatiereeks Gevaarlijke Stoffen*) on battery safety that is currently under development and to its predecessor, the Circular on Energy Storage Systems (*Circulaire EOS*) – both of which explicitly state that they do not apply to EVs. Much like the standards and regulations for EV batteries, PGS 37 and the Circular address safety measures such as traceable high-quality cells, BMS functions, cooling, sufficient distance between units, mechanical protection and the provision of information to emergency services. The standards and regulations for EV batteries are more specific and stricter than those laid down in PGS 37 and the Circular.

2.3.3 Risks

A damaged battery can eventually lead to thermal runaway, resulting in toxic smoke and fire. Thermal runaway is the self-perpetuating process of undesirable chemical reactions (due to internal damage) in the battery that generate extreme heat. Battery damage can also lead to electrical hazards, such as short circuits or electric shocks. Since too few practical tests have been carried out, it is currently impossible to say whether these risks are greater for logistics EVs than for passenger EVs.

But for all EVs, the following question applies: How can you recognise an internally damaged battery pack (without external deviations)? It is likely that OEMs are already in the process of making the BMS smarter for this purpose, but there is no publicly available information on this (and the interviewees also had no information). It is recommended that standards and regulations pay more attention to these advanced BMS functions for improving battery safety. This will also help retrofitters to make the battery work more efficiently and safely.

2.4 Fire safety

Fires in electric vehicles have the potential – when the battery is involved in the fire – to have a significant impact on the vehicle and the surrounding area, especially as they are more difficult to extinguish than fires in vehicles with internal combustion engines. Standards and regulations, as well as appropriate designs and correct usage, help to adequately reduce and/or mitigate the risks.

A fire can occur in the vehicle's battery pack due to internal faults, such as internal cell failure or overheating, a short circuit or overcharging. An external factor may also be the cause of a fire: fires can originate elsewhere in the vehicle, there might be an external fire (e.g., in a petrol vehicle) or a mechanical impact, such as a collision or an incident on a construction site. Thermal runaway releases flammable and toxic gases from the battery, which pose a potential fire or explosion risk. The requirements and measures are the same as those for e-buses.

Fire safety during charging is discussed in the 'Charging infrastructure' section.

2.4.1 Existing research

DNV is not aware of any specific research that focuses on vehicles in the logistics sector. The most relevant report is the IFV report on the fire safety of e-buses [17].

2.4.2 Laws and regulations, standards and safety requirements

The fire safety requirements for batteries are the same for passenger EVs, e-buses, e-trucks, etc. (see also Section 2.2.2). As discussed in Section 2.2, the umbrella organisation for Electric Vehicle Safety (EVS-GTR) is currently preparing a third revision of the ECE R100 regulation [30]. The expectation is that this will include additional tests for fire safety, fire propagation, immersion in water, etc.

2.4.3 Risks

2.4.3.1 Fire load

The risks in the event of a fire in a passenger EV are estimated to be comparable to those of an ICE vehicle, as evidenced by the studies cited by CE Delft [1]. The temperature curve, the fire load and the quantity and nature of the toxic gases involved are all similar. This is mainly because other parts of the vehicle (e.g., hydraulics, upholstery, plastic parts, sheet metal) will also burn in the fire. Although the behaviour of an uncontained fire is similar, one disadvantage of a Li-ion fire is that the fire can flare up again once the flames have been extinguished and it can also reignite hours later [31], [32], [33], [34], [35], [36]. This means that more fire extinguishing water and more firefighters are needed to control a Li-ion fire. The IFV reports that, for buses, the fire behaviour and fire load of electric and diesel vehicles are also comparable [17]. The same is expected to apply to logistic vehicles. More research is required for e-buses and e-trucks to further quantify the similarities and differences between EVs and non-EVs. A possible complicating factor here is that battery packs in logistics vehicles can be located in several places in and on the vehicle.

CE Delft has also shown that incidents involving passenger EVs occur less frequently than those involving fuel-powered cars, even when correcting for the lower number of EVs currently on the roads [1]. Given the relatively small numbers involved, it is still unclear whether this will also be the case for e-trucks or e-buses.

In the case of logistics vehicles, the load being transported can also have an effect on the vehicle fire, depending on the type of load. A fire in the load can lead to a fire in the fuel tank or in the battery; likewise, a fire in the fuel tank or in the battery can spread to the load. DNV has not been able to find any research literature on this issue. The OEM will initially have to look at a risk analysis of this situation. In this regard, for both ICE vehicles and EVs, constructive barriers ensure that a fire in the drive system cannot easily spread to the load (or to the cabin).

2.4.3.2 Organisation of logistics sites

On a logistics site – open or covered – many electric trucks can be parked next to each other. As yet, we still know very little about and have limited experience in determining safe distances between vehicles for preventing fire propagation. It would be advisable to develop guidelines regarding permitted distances to prevent the spread of fire to an adjacent vehicle. But to do this, we first need to acquire more knowledge.

2.5 Incident management

Incident management involving heavy-duty electric vehicles requires a different approach to that of passenger EVs. By and large, the approach to tackling a fire is similar to that of passenger EVs [1]: keep your distance, switch off the system, cool with large amounts of water, be prepared for thermal runaway, take into account reignition, identify the situation and type of vehicle and disconnect the power. The big difference, however, is that the battery pack is significantly larger, which means there may be more energy in the battery pack; larger vehicles do not fit in an immersion container and/or salvage container; and some of the vehicles are retrofits.

Emergency services are exposed to the same risks when dealing with incidents involving logistics vehicles as they are in the case of passenger EVs. The probability of receiving an electric shock when providing assistance is very low, because the likelihood of any live parts of the battery being exposed is minimal. In addition, gloves and uniforms currently used by firefighters offer sufficient electrical protection, even against high battery voltages of up to 1,000 V [37].

Fire services use rescue sheets [38] so that they have all the relevant information to hand during incident management. The EURO-NCAP requirement, a four-page information document, is only available for passenger EVs. The Moditech crash recovery system [39] used by fire services indicates the location of hazardous components and also contains information on electric vans and trucks – but this is not complete.

In severe collisions, the battery of an EV can become damaged and spontaneously combust. Incident management for electric passenger vehicles on main roads has been regulated since 1 June 2021 [40]. A procedure has also been developed for the safe salvaging of EVs – using an open immersion container for submerging an extinguished EV in water or a salvage container (a closed container fitted with an extinguishing system on stand-by) for EVs with batteries that appear to be undamaged. Unfortunately, these containers are too small for e-buses or e-trucks. Therefore, for these larger EVs, alternative salvaging methods will have to be explored, which is in line with CE Delft's conclusions in its research into the safety of e-buses [2] . On a smaller scale, several extinguishing methods are already being explored. [41].

The current generic procedure for EVs is in need of an update for electric logistics vehicles, both in terms of instructions for the driver and of information for incident responders and salvage companies regarding possible courses of action.

Incident monitoring

There have been very few incidents involving electric trucks, at most a few near misses, i.e., minor collisions without significant damage. This is primarily attributable to the low numbers of logistics EVs on the road at present. The IFV has been monitoring incidents involving alternatively powered vehicles since January 2021 [42]. The database is populated (using questionnaires) with data on incidents involving alternatively powered vehicles and on how they were handled. This concerns incidents involving the fire service. Fire services' Fire Investigation Teams use the questionnaire not only for investigating the incident at the scene, but also for the follow-up call to the relevant commander, duty officer or hazardous substances advisor about the incident. It is vital to gain an understanding of the facts and of how an incident developed. These lessons learned should be shared widely and could be used to improve technology, set effective safety requirements, improve processes and provide good information / offer effective training courses so that people become more aware of the dangers and behave in a safer manner.

The data from the Integrated Control Room System (GMS, *Geïntegreerd Meldkamer Systeem*) is connected to the data from the STAR (Smart Traffic Accident Reporting) accident database of VIA, a traffic research and IT agency. VIA keeps track of all traffic accidents in the Netherlands on behalf of the police and the Dutch Association of Insurers. This link facilitates the recording of as many traffic accidents involving alternatively powered vehicles as possible. This data is collected in the online dashboard, which displays the most important figures [43]. The dashboard only includes incidents in which the fire service is involved; however, we recommend expanding this database to include data from insurers so that lessons learned from near misses can also be included. However, the question remains as to how feasible this is in practice and which organisation could assume responsibility for it.

2.5.1 Existing research

Supported by an international team of experts, Kurt Vollmacher (the Belgian fire service) has drawn up a set of recommendations for passenger vehicles and light commercial vehicles [44]. As a project leader for ISO/ TC22/ SC36/ WG 7, he has contributed to the drafting of global standards on safety information for EVs. This document was compiled by international experts who interviewed 425 emergency responders from various countries to collate their knowledge and experiences. Emergency responders need to be able to clearly identify and have access to information about all EVs on public roads. The document provides recommendations for identification markings on the EV and its battery, uniform and globally available information on each EV, a uniform and simple shut-off system installed in the same place in all EVs, systems that can quickly extinguish batteries, safety tools and procedures to safely deal with high voltages and energy, and guidelines on how to handle EVs in car parks. Although the majority of the emergency responders interviewed by Vollmacher et al. have not yet experienced a fire involving an electric vehicle, they do have concerns. It is precisely this lack of practical experience that poses the risk of mistakes being made.

The recommendations made in the report are [44]:

- Attach clear identification markings to electric vehicles and their batteries.
- Impose standardised technical solutions, with a standard location for the battery packs and a uniform and easy-to-operate switch-off system for all EVs to ensure electrical safety.
- Introduce standardised procedures for emergency assistance and fire fighting.

These recommendations are relevant for electric vehicles in the logistics sector since retrofits are difficult to recognise and the location of the battery packs is not always clear.

2.5.2 Laws and regulations, standards and safety requirements

There are no specific laws and regulations for electric vehicles in the logistics sector.

2.5.3 Risks

2.5.3.1 Availability of information

EURO-NCAP [45] requires a four-page information document on the risks of passenger EVs, but not of e-buses and e-trucks. The Moditech crash recovery system does cover trucks, but this information is incomplete. Vollmacher et al. also observe a lack of uniformity in the provision of information and call for an internationally standardised information system [44].

BOVAG has announced that it is developing a system for relaying information on vehicles within the chain (bodybuilder, dealer, garage, etc.). They intend to either collect this safety information (information about the location of the battery, etc.) themselves or ask the dealers and bodybuilders to do so, and make it available to emergency services, possibly via a QR code on the vehicle.

2.5.3.2 Knowledge sharing

As things stand, vehicle suppliers do not always permit independent investigations of incidents; the lessons learned from such investigations could be incorporated into standards and norms. It is vital that lessons learned are shared more widely than just within the EV supplier internally.

2.5.3.3 Experience

There is a great deal of diversity when it comes to logistics EVs, which means that information documents have to be downloaded and understood every time there is an incident. A more uniform protocol could speed things up. Furthermore, each Safety Region is responsible for training and educating its own personnel. The challenge here is that many of these people are volunteers, so there is only limited amount of space and time in which to provide adequate training to emergency responders. For this reason, each Safety Region has appointed it own in-house experts to manage and stay on top of the knowledge acquired and experiences gained. It takes time to build up knowledge and to train people, so it is important that efforts are stepped up now, before EVs are rolled out on a larger scale.

2.5.3.4 Terminology

Interestingly, the automotive sector and the electricity sector use different terminology for high and low voltage. According to NEN 1010 [23], low voltage is: alternating voltage up to 1,000 VAC and direct voltage up to 1,500 VDC. However, this low voltage and the voltage in electric vehicles is NOT safe to touch. A voltage level below 50 VAC or 120 VDC is not considered dangerous according to NEN 3140 / EN 50110 [46]. In the automotive sector, low voltage refers to a direct voltage of up to 48 VDC. The battery for the drive, with a voltage between 200 VDC and 1,000 VDC, is referred to as a high-voltage battery.

2.5.3.5 Immersion and salvage containers

There is currently no solution for storing a burnt e-truck (or e-bus) safely for the long term: larger vehicles do not fit in the immersion and salvage containers. Rijkswaterstaat is responsible for salvaging vehicles on motorways. Therefore, we recommend developing protocols and resources for safeguarding e-trucks.

There are several potential solutions:

1) The OEM must implement measures that prevent a battery fire from spreading to the load, the trailer and the driver's compartment.
2) Develop alternative methods of channelling fire extinguishing water to the battery.
3) Develop protocols for safeguarding a vehicle, for both during and after the fire, so that disruption to emergency services’ operations and other traffic is kept to a minimum.

2.5.3.6 Information sessions

The interviews revealed that there is a significant difference between e-buses and e-trucks in terms of information provision. Since buses tend to operate in a particular municipality, it is easy for OEMs to organise an information morning for the local fire service. However, e-trucks operate in several municipalities, so this approach is ineffective.

2.6 Enclosed spaces

Tunnels are part of public roads and may therefore be used by all vehicles with a regular registration plate (however, there are regulations in place for the bulk transport of fuel). Emergency situations in tunnels involving battery fires may have a more severe impact than fires involving ICE vehicles. The (brief) intensity of a battery fire may damage the tunnel wall, fire extinguishing water may become contaminated and any toxic and explosive gases must be extracted safely.

Although the expectation is that logistics and construction vehicles will not or will rarely be parked in garages, EVs in tunnels are a particular concern.

Dutch building regulations, standards and guidelines are based on the characteristics of fires involving conventional vehicles. However, modern vehicles have a higher fire load and fire capacity than older steel models, partly due to the widespread use of plastics. In the last few decades, electric vehicles – including recharging them – have also become more common [47]. Research into tunnel fires is, therefore, in need of an update in order to account for the impact of modern vehicles, including battery-powered electric vehicles.

2.6.1 Existing research

DNV is not aware of any research that specifically addresses e-trucks. The IFV's study on the fire safety of e-buses in tunnels [17] indicates that, in terms of fire load and the amount of toxic substances released, fires involving passenger EVs do not differ significantly from fires involving ICE vehicles. However, the IFV points out that the same comparison is yet to be carried out for buses (and trucks). Fire tests conducted as part of the FFG-funded project ‘BRAFA - fire effects of vehicles with alternative drive systems' [48] have shown that Austrian tunnels are suitable for EVs [49]. This study focused on passenger EVs; e-trucks were not addressed. The researchers concluded that further research into tunnel fires involving e-trucks is urgently needed. Mellert et al. [50] also focused on the risks of electric vehicles catching fire in tunnels and concluded that the most advanced tunnel ventilation systems are able to cope with the fire load, but, again, e-trucks were not addressed in this study and further research is required.

2.6.2 Laws and regulations, standards and safety requirements

The issue of storing flammable substances has been addressed for automotive fuels in PGS 26 and for hydrogen in PGS 35. PGS 37 for 'Lithium-ion batteries: storage and district batteries' is also in preparation. Although this does not cover battery-powered electric vehicles, it does contain general recommendations that are also relevant to heavy-duty electric vehicles.

2.6.2.1 Tunnels

Rijkswaterstaat manages QRA tunnels pursuant to the Additional Rules for Road Tunnel Safety Act (Warvw, *Wet aanvullende regels veiligheid wegtunnels*). This includes the first calculations for hydrogen buses. Our recommendation is to develop a similar analysis for electric logistics vehicles. A limiting factor here is that the underlying data for substantiating such a QRA barely provides any statistical evidence at this stage.

Furthermore, a better understanding of the specific hazards of electric trucks (and buses) in tunnels is needed in order to properly assess the tunnel safety of these EVs. This mainly concerns the physical aspects of burning batteries in trucks and buses (fire capacity, maximum temperature, quantity of toxic substances, the course of the fire (peak)) [17] and how this relates to the burning of other parts of the vehicle (e.g., hydraulics, upholstery, plastic parts, sheet metal).

Incident management in tunnels is also a major concern. Knowledge of the specific hazards of electric trucks in tunnels must then be translated into possible courses of action. If battery packs are located in a hard-to-reach area, it may be more difficult and take longer to extinguish the fire (also in tunnels). For example, if the battery pack in an electric truck is located underneath the vehicle, the firefighters may need to tilt the vehicle in order to adequately extinguish the fire, which is difficult to do with large vehicles.

2.6.2.2 Garages

Currently, the fire risks posed by passenger electric vehicles, including electric delivery vans (category N1), in multi-storey car parks are the focus of much attention. The existing regulations for multi-storey car parks do not currently include specific fire safety requirements for electric vehicles and charging facilities [51]. The Ministry of the Interior and Kingdom Relations is planning to add several regulations for new multi-storey car parks; the internet consultation for this issue closed on 15 August 2021 [52]. The new regulations are expected to include provisions on charging stations in multi-storey car parks. Some countries (e.g., France [53]) have regulations for multi-storey car parks which, for example, only permit EV charging stations to be installed near the entrance on levels 0 and 1. According to RISE [54], a parked EV that is being charged is not at a greater risk of catching fire than a parked EV that is not being charged.

Similar considerations are also relevant for parking and charging logistics EVs in covered depots. Regulations should be developed concerning the location of the charging stations in the building and the height of the building. It is unlikely that a building or an apartment block will be constructed on top of such a depot, so issues such as consequential damage to the supporting structure are less relevant.

2.6.3 Risks

2.6.3.1 Suitable equipment

A major risk associated with fires (involving EVs or otherwise) in enclosed spaces is the accumulation of smoke, which makes it virtually impossible for emergency services to access the situation. During a fire in a multi-storey car park in Alkmaar (1 July 2020), fire-fighting robots were deployed, and a police transport robot was able to assist in the salvaging of an EV [55]. Robots could also be used to help assess the situation and handle incidents in tunnels safely.

2.7 Charging infrastructure

Logistics EVs with charging capacities of up to 350 kW use the same charging infrastructure (AC and DC) as passenger EVs. Companies expect that charging will mainly take place using private or semi-public charging infrastructure, i.e., on company premises [56]. Depending on the grid capacity at these locations and the type of truck, AC or DC charging infrastructure, or a combination of the two, can be used. As a general rule, capacities of up to 50 kW are sufficient for overnight depot charging and higher capacities between 50 and 350 kW are needed for fast charging during the day or while en route [57]. Charging infrastructure on private and public land is based on the same standards and protocols. When charging infrastructure is applied and used correctly, no additional safety risks were identified for charging logistics vehicles compared to passenger cars.

Some of the interviewees noted that the quality of the existing installation for charging logistics vehicles occasionally leaves something to be desired. The power demand of a logistics vehicle is generally greater than that of a passenger EV due to the larger battery, and the charging time is longer. Consequently, this must be taken into account in the installation (correct dimensioning of cables and switches), which must be carried out in accordance with NEN 1010.

Category N3 vehicles may require greater capacities than 350 kW, similar to charging buses. When it comes to opportunity charging, e-buses are charged via a pantograph with capacities of up to 600 kW. The physical pantograph coupling has been developed specifically for e-buses but could also be adapted for e-trucks. Communication between charger and vehicle is wireless, but the protocol used is IEC 61851-1 or ISO 15118, as with standard DC charging stations. A global standard (Megawatt Charging System, MCS) is currently being developed that will enable charging with capacities between 1 and 4 MW [14]. A public MCS network like this can serve as a back-up for the logistics sector. This is also listed as one of the Logistics Top Sector's basic requirements.

An alternative solution for charging trucks is to install charging stations along motorways or other through roads. Charging stations are then often located on the premises of existing petrol stations or lorry parks. A petrol station with charging stations is referred to as a Multi-Energy Station (MES) [58]. The primary concern in terms of safety is the location of charging stations in the vicinity of hazardous areas (ATEX rules) [59]. The applies for both logistics EVs as for passenger EVs.
It is important that charging infrastructure for logistics comply with the appropriate spatial requirements. In terms of safety, this primarily concerns obstacle protection such as wheel chocks and collision protection (e.g., bollards) and a clearance height of at least 4.2 metres [11].

2.7.1 Existing research

Since the introduction of passenger EVs, a number of studies on charging infrastructure have been conducted, some of which also focus on the logistics sector [12] [60] [11] [61]. This mainly concerns the supply and type of charging infrastructure required for a comprehensive network. Safety aspects are addressed by using international standards and protocols that were developed for the passenger electric vehicle industry and applied directly in the logistics sector (e.g., the Combined Charging System (CCS) for DC charging).

2.7.2 Laws and regulations, standards and safety requirements

The main standards for charging infrastructure are IEC 61851: Electric vehicle conductive charging system [62] and IEC 62196: Plugs, socket-outlets, vehicle connectors and vehicle inlets – Conductive charging of electric vehicles [63]. All current charging stations and cables/plugs comply with these standards. The MCS, which is currently still under development, can be regarded as a standard specifically for the logistics sector due to the high capacities.

In addition to correct installation according to NEN 1010, a safety inspection/maintenance is required at least once a year (applies to all EV charging infrastructure in general). This is not centrally regulated or compulsory, but most charge point operators (CPOs) do follow this guideline.

2.7.3 Risks

When used correctly, the charging infrastructure itself does not pose any additional safety risks when compared to charging infrastructure for passenger EVs as it is based on the same standards and protocols. It is important that employees are well informed about the use of charging infrastructure through, for example, a short training course.

In the event of a fire, high-capacity installations such as those planned for the future (ranging between 1 and 4 MW) present a possible risk of electrocution for firefighters when cutting and extinguishing [64]. Cutting the charging cable should be avoided, and extinguishing should only take place once the installation has been disconnected from the power supply.

Potential risks related to the charging station include collisions with the charging infrastructure and overloading of the network equipment. Heavier logistics vehicles can knock over charging stations more easily than passenger electric vehicles. This is particularly the case in depots where many trucks manoeuvre around a relatively small area. If the cabling becomes exposed after a collision and there is still voltage between the charging station and the mains connection, this poses a safety risk. This can be prevented by equipping the installation with suitable collision protection so that it cannot be knocked over easily and by configuring the charging station in such a way that it automatically cuts off the power in the event of a collision or other incident.

There is a risk of the installation being overloaded if it is not correctly dimensioned and installed. The risk of this happening is greater for installations for e-trucks than for personal electric vehicles on account of the sustained demand for energy at a high capacity. It is important that installations are completed in accordance with the NEN1010 standard, ideally by installation companies with experience in installing charging infrastructure.

2.8 Noise and absence thereof

The engine in logistics ICE vehicles produces a significant amount of noise. When the drive is powered by electricity, this noise is eliminated. Electric vehicles are, therefore, less likely to be noticed at lower speeds, which may pose an additional safety risk, particularly in the case of delivery vans and larger trucks.

2.8.1 Existing research

There is a range of research available on EVs and noise (see, for example, [65]). This does not focus specifically on logistics vehicles.

2.8.2 Laws and regulations, standards and safety requirements

Since July 2021, all new electric and hybrid vehicles with four wheels must be fitted with an Acoustic Vehicle Alerting System (AVAS), in accordance with EU regulations. These regulations also apply to vehicles used in the logistics sector.

They stipulate that electric vehicles must emit a sound between 56 and 75 decibels (dB) when travelling slower than 20 kilometres per hour (also when reversing). This is usually a buzzing or humming sound (not an alarm signal) which varies depending on whether the vehicle is moving forward, reversing or stationary. The type of sound can vary from OEM to OEM. At speeds above 20 kilometres per hour an EV ultimately produces sufficient noise from the tyres and the wind, rendering such a system unnecessary.

2.8.3 Risks

The interviews revealed that the feedback from drivers regarding the lack of noise when driving logistics EVs is rather mixed. The drivers can hear their surroundings more clearly (because their own vehicle produces no noise), but other road users cannot hear them sufficiently or at all. The effectiveness of an AVAS in preventing accidents remains to be seen in practice. However, it is reasonable to assume that an AVAS will adequately compensate for the potential risks of a quieter EV, especially as such systems will continue to be improved based on practical experience.

2.9 Other safety aspects: behaviour and processes

The most crucial aspect when it comes to safety is people and their behaviour. Awareness of the risks when operating EVs dictates whether the regulations and processes are followed. The topic of people and their behaviour touches upon various aspects during the everyday use, construction and maintenance of electric vehicles: awareness of and behaviour regarding charging, skills/expertise and certification to prevent unskilled repairs, the handling of exchangeable battery packs and the proper use of PPE. In this respect, in the logistics sector DNV identifies fewer safety risks in everyday use, but more challenges in terms of maintenance.

OEMs would ideally like all dealerships to have an EV expert on hand to provide sound information about safety during the sales process. Volvo said that it offers a three-day training course for garage staff to teach them how to deal with E-trucks in the workshop. Some parts of the training course are also offered to everybody who works there, from the cleaners to the management team – to ensure that the management team takes safety into account when making decisions and that the cleaners do not create an unsafe situation.

Equally important are the processes used to ensure safe working practices, for example, processes for monitoring the inflow and storage of EVs but also the handling of battery packs for retrofitting, maintenance, the revision of current work procedures and incident management (section 2.5).

2.9.1 Existing research

DNV is not aware of any research regarding the processes and behavioural aspects regarding EVs in the logistics sector.

2.9.2 Laws and regulations, standards and safety requirements

Personnel who work on electric vehicles must comply with NEN 9140 [24]. NEN 9140 [66] is based on NEN 3140: 'Operation of electrical installations – Low voltage' and describes the requirements for the instruction and training of electrically trained personnel and the activities that non-electrically trained personnel are and are not allowed to perform. The standard focuses on the new risks of hybrid and electric vehicles, where unskilled intervention can lead to serious damage and injury, because voltages of many hundreds of volts (up to 1500 V in the case of MSC) are involved. BOVAG and the RAI Association are currently developing a label (certificate) that goes beyond NEN 9140, with additional and more specific requirements. This is expected to be rolled out in 2022.

2.9.3 Risks

2.9.3.1 EV expertise

There is little knowledge of EVs (charging and battery safety) in the logistics and construction sectors. While major players can employ in-house experts, smaller companies are not always able to do so. Consequently, smaller companies might struggle to have sufficient in-house knowledge to be able to operate safely and provide proper information.

Skills and expertise are crucial for preventing unskilled repairs, which can lead to unsafe working conditions.

2.9.3.2 Trucks

Safety risks associated with e-trucks may arise in bodywork construction in particular: elements such as a crane or cargo body are often mounted in the Netherlands on the supplied electric chassis. This means that welding and screwing activities still need to take place. There is no universal standard design for chassis. As a result, assembly guidelines are very brand-specific and are not always followed to the letter. Bodybuilders have access to certain interfaces (attachment points, couplings, plugs), but sometimes it is easier to do things differently. Additionally, they are generally not allowed to work on the batteries themselves. Although service bulletins can be distributed among technicians, for the moment OEMs prefer to have their own specialists who support and train bodybuilders.

NEN 9140 addresses working safely on all types of electric vehicles. It is essential that the truck community becomes aware of the need to implement the requirements of NEN 9140 in terms of work procedures, training and documentation. OEMs can and must support the maintenance companies and bodybuilders with their knowledge and experience, as is already the case for the safe use of vehicles. It is unclear whether the parties involved also provide such support during the bodybuilding, particularly when extra batteries are fitted on the body.

2.9.3.3 Availability of sufficiently trained personnel

The limited knowledge of electrotechnology in the automotive industry is a barrier to obtaining proper in-house expertise. Raising awareness among and training technicians is essential to ensure that they can recognise when their own knowledge is lacking and they need to call in external expertise.

The current procedure whereby OEMs train their customers separately is perfectly feasible in the current start-up phase, as sales volumes are still low. The risk is that, in the future, many more people will be needed (trained and trainers), and the specialist training will then have to be offered more broadly.

2.9.3.4 Loading weight

Unloaded electric trucks are heavier than ordinary trucks due to the weight of the batteries. A 300-600 kWh battery pack weighs around 1 to 2 tonnes. The type approval is valid for the total weight of the vehicle. For many new vehicles, the display in the cabin indicates whether the total load has reached its maximum level. The extent to which truck drivers comply with this, or carry on loading anyway, is unknown.

2.9.3.5 Behaviour

Changing behaviour and raising awareness is a complex undertaking. In practice, people are often only willing to change their behaviour after they themselves have witnessed something (almost) go wrong. In light of several interviews and DNV's own experience with various new technologies in a range of sectors, we recommend setting requirements for the expertise needed to manage and deal with e-trucks and providing training/refresher courses for all staff (drivers, cleaners, technicians, management, etc.), during which the risks are repeatedly discussed.

3 CONSTRUCTION

3.1 Scope

This section focuses on all electric mobile machinery, vehicles and equipment used in the construction industry with a capacity of 8 kW or more and powered by a battery pack. The construction section of this report primarily discusses battery-powered mobile machinery.[8] Generally speaking, battery-powered construction vehicles on public roads are subject to the same considerations (risks, conclusions, recommendations, etc.) described in this report as logistics EVs of a similar size. If these construction vehicles are located on a building site, for the purposes of this study they are generally comparable to machinery. In this study, the term 'construction' covers non-residential construction and ground, road, water and housing construction, both in the inner city, where there is already infrastructure in place, and in spaces outside the city.

The current range of products on the market is a mix of hybrid, battery-powered and mains-powered electrical equipment. Battery containers (energy storage systems) are a significant new component for the supply of electricity on construction sites and are, therefore, also discussed here. Material handlers are not mobile and are, therefore, not covered in this study.

Electric models of mobile construction machinery that are currently commercially available can generally be deployed for a working day, depending on the size of the battery [67].

Government bodies and municipalities impose strict requirements on machinery, and zero-emission is a key issue here. The uptake of battery-powered equipment is largely driven by technological developments, the construction site and requirements of the commissioning party/licensing authority [68]. Electric excavators are currently associated with a significantly higher investment than ICE models. In addition, the supply of electric machinery and excavators is still limited, and a major breakthrough is not expected until around 2025; large OEMs such as Caterpillar and Volvo are on the verge of entering the market, driven in part by international emission standards. ElaadNL [68] predicts that, by 2035, there will be between 15,000 and 37,000 battery-powered machines in circulation; for comparison, today's fleet of construction machinery (electric and ICE combined) is estimated to comprise around 55,000 machines. Retrofitting has the potential to be a good alternative for satisfying current demand for electric construction machinery.

3.1.1 Categories

Table 3-1 Overview of electrically powered construction machinery Based on the overview by BMWT [67].

Category	Model	Example
Shovels (wheel loader / loading shovel / earth-moving machine)	Machinery weighing less than 8 tonnes are all battery-powered. Above 8 tonnes, currently only one type available.	

[8] Where this report mentions 'mobile electrical machinery', this refers to battery-operated mobile electrical machinery.

Category	Model	Example
Excavators (mini)	Battery-powered. Battery pack size comparable to passenger EVs.	
Excavators (wheels/crawlers)	Available in hybrid, battery- and mains-powered versions, weighing between 10 and 120 tonnes. Heavy machines mainly charge via a power cable. Currently one model weighing 26 tonnes with ~300 kWh battery pack, Caterpillar	
Telescopic handlers (forklift that can negotiate rugged terrain)	Weight and battery pack comparable with smaller excavators.	
Vibratory plates and rammers	Currently one brand on the market. Battery pack is small compared to passenger EVs (0.5 - 1.5 kWh).	
Battery containers	Size can vary between 50 and 2000 kWh depending on energy demand. Prevents overloading of existing installation.	

Category	Model	Example
Bulldozers	Weight comparable to excavators. Currently no battery-powered version available on the market.	
Electric asphalt paver	First prototype with LFP battery packs [69].	

Photo sources: Ahlmann, Kubota, Van Oord, Manitou, Wacker Neuson, Reco, Caterpillar, KWS.

3.1.2 Laws and regulations on the construction site

The contractor of a construction project is responsible for safety on the construction site and is expected to have a safety system (rules and methods that promote safety) and a health and safety plan (H&S plan) in place. Additionally, the Working Conditions Act (Article 3) obliges employers to safeguard the health and safety of employees in all areas related to work, including work equipment such as mobile equipment. These must be inspected at least once a year to prevent them from becoming unsafe due to wear and tear or age. The employer is free to decide who will inspect the equipment, as long as the inspection is carried out by a competent person or institution. This might be an independent inspection agency, a supplier's maintenance department or the company's own technical department. The inspectorate from the Ministry of Social Affairs and Employment (SZW) monitors compliance. The National Guidelines on Construction and Demolition Safety (*Landelijke richtlijn Bouw- en Sloopveiligheid*) issued by the Netherlands Association for Building and Housing Control (*Vereniging Bouw- en Woningtoezicht Nederland*) [70] also contain general rules regarding safety on construction sites. Guidelines on mobile storage systems on construction sites can be found, for example, in the Electricity Storage Systems Manual (*Handreiking Elektriciteit Opslag Systemen*) published by the Rotterdam-Rijnmond Safety Region [71].

Legislation on Li-ion batteries will change in 2022:

- Batteries Regulation [29] (proposal dated 10 December 2020)
    - Producer responsibility: all batteries that an importer or producer introduces on the Dutch market have to be reported to the government or a collective organisation.
      Aim: the entire chain – up to and including the last stage (waste stage, i.e., recycling) – must be registered with the Ministry.
    - There is also an obligation to collect those batteries and report the quantities. This will make it possible to determine the percentage of batteries recycled. The Netherlands must report this to the European Commission.
    - The Environment and Transport Inspectorate (ILT; *Inspectie Leefomgeving en Transport*) has announced that it will assume the role of providing information.

Parties in the market are currently in the process of arranging RDW registration (> 6 km/h) for electric mobile machinery that also drives on public roads. In addition to a registration certificate, an inspection is also required.

3.2 Vehicle safety

3.2.1 Existing research

DNV has not found any existing research that specifically focuses on safety risks for electrically driven construction machinery.

3.2.2 Laws and regulations, standards and safety requirements

Since 1 January 2021, larger mobile machinery in the construction industry is also subject to the registration requirement (*Kentekenplicht*) – for example, excavators, loaders and similar mobile machinery. This requirement does not apply to machinery that is not used on public roads, such as excavators and machines that are transported in separate parts to the construction site by specialist transportation. These do not have to be inspected by the RDW.

The branch organisation BMWT performs regular safety inspections of machinery such as road construction machinery and transport equipment. However, this inspection is not compulsory (no checks are carried out). BMWT offers a specific inspection for batteries and charging infrastructure. This is essentially a visual check of aspects such as the condition of the battery, the BMS and the charger/charging cable. Electric vehicles are rapidly emerging on the market, so it is vital to update the inspection system in good time and to ensure that it is kept up to date.

3.2.3 Risks

Conditions on a construction site differ from those on a public road: sand, dust, mud, puddles of water, stones and other obstacles, potholes and bumps. Moreover, there is often heavy traffic in a relatively small area. Possible risks to the operator and the environment include:

- Stability – better with a low-positioned battery, worse with a high-positioned one due to extra weight
- Easier acceleration, which can result in unexpected movement – the BMS can/should limit this
- Risks to the battery (and, therefore, indirect risks to the operator and the environment)
- Rubble on the undercarriage – the battery can and must be protected against this
- Impacts that can damage the battery – not due to high speed but due to other mobile machinery or loads falling.
- Dust and moisture penetrating the battery

It can be assumed that electric mobile machinery supplied directly from the OEM have been fully tested for safety and pose no additional risk compared to current ICE models. However, it is advisable to train operators of electric mobile machinery in the following aspects: stability differences, greater acceleration and safe recharging. All workers on a construction site (who may have to deal with electric mobile machinery and vehicles in any way) should also receive extensive training on the risks of electric mobile machinery and vehicles: e.g., issues relating to collisions and falling loads. For retrofitted electrical mobile machinery and machines to which additional battery packs have been fitted, there is a risk that the machine has different safety characteristics that require different mitigation measures than those envisaged in the original design. There is a risk that these retrofitted/mounted mobile electrical machinery will not be adequately inspected or tested.

3.3 Visible and invisible battery damage

In the construction sector, there is a very wide range of mobile electrical machinery and corresponding batteries available. For the well-known manufacturers, the same applies as for logistics EVs: the batteries are similar to or based on batteries used in passenger EVs that have been developed according to high automotive quality requirements.

The situation is different for retrofitted machines: in this case, the batteries may be less well protected due to lower quality requirements. Damage could also occur as a result of unskilled repair and overhaul activities.

If exchangeable batteries are used, they need to be made robust and there must be clear instructions on how to handle them. In this regard, awareness-raising and training are crucial.

As mentioned with respect to logistics EVs, an effective BMS will use deviations in cell voltages, local temperatures and measured shocks and vibrations to provide an indication of the safety condition of the battery. Where necessary, the BMS should then prevent the battery and electric mobile machinery from being switched on and issue a warning that the battery must be replaced immediately.

3.3.1 Existing research

DNV has not found any studies that apply specifically to electric mobile machinery (see also 2.3.1).

3.3.2 Laws and regulations, standards and safety requirements

For batteries in construction machinery, the same applies as for logistics, see 2.3.2. Moreover, in the construction industry in particular, it is important to include clear rules for handling electric mobile machinery and (exchangeable) batteries in the work instructions.

The mobile charging station with battery forms a separate category; this is usually a battery container with connection points for charging electric mobile machinery and vehicles (and possibly other battery packs). This type of installation is not an EV or electrical mobile machine itself, but an energy storage system, which is subject to the Circular on Energy Storage Systems (*Circulaire EOS*) and the future PGS 37 (*Publicatiereeks Gevaarlijke Stoffen*).

3.3.3 Risks

In the construction sector, there is generally a higher risk of an electric mobile machine or battery colliding, falling or bumping against something, which can affect both batteries inside the machine and any exchangeable batteries on the outside. Several interviewees indicated that the first safeguard against this is to ensure that the battery is mechanically robust. OEMs will have probably taken the necessary steps to ensure this, but for retrofits this may not be the case.

Similar to logistics (2.3.3), the BMS can play a role in construction to monitor and report invisible internal battery damage, but this is still an underdeveloped area. In construction, the development of a method for detecting whether a battery has been damaged (and, therefore, whether additional measures need to be taken) is perhaps even more important, as the likelihood of this happening is thought to be greater in this sector.

3.4 Fire safety

The fire safety of heavy-duty electric mobile machinery used in construction is generally no different from that of logistics vehicles. However, the environment in which the machinery operates poses an additional challenge. Due to the dusty environment, dust could cause problems in the battery pack. As such, a sufficient IP rating is critical; it must be at least IP 66 (dustproof and water-resistant). This is the same rating that OEMs specify for their batteries.

Fire-safety issues related to the surrounding area include: extinguishing/cooling capabilities, risks to site personnel (the fire may be difficult to extinguish; evacuation may be required), disruption of the construction process, risk of the fire spreading to structures.

3.4.1 Existing research

DNV has not found any existing research that applies specifically to electric mobile machinery.

3.4.2 Laws and regulations, standards and safety requirements

For electric mobile machinery, the same applies as for logistics, see 2.4.2. Moreover, in the construction industry in particular, it is important to include clear rules for handling electric mobile machinery and (exchangeable) batteries in the work instructions.

3.4.3 Risks

3.4.3.1 Mobile charging containers

The fire service is often unaware of the presence and location of electrical mobile machinery and mobile battery containers. The fire service can give solicited and unsolicited advice, but in practice is often unable to do so because it is not kept informed. Energy storage systems must be reported to the grid operator; the fire service would also like to be notified. In any case, it is important that these charging containers are recognisable as such by the use of signs and/or stickers [44]. An electric mobile machine is not regarded as an energy storage system.

3.4.3.2 Moving machinery

During the interviews, a key observation was made about moving electric construction machinery. As the current charging capacity on a construction site is often limited, the lighter electric mobile machines are usually transported back to their base (by a diesel truck) at the end of the day for recharging. This poses additional risks on the road due to the additional journeys and the large quantity of electric mobile machinery that is charged overnight at the base at the same time.

3.4.3.3 Impact of a battery fire on the structure of the building under construction

On a construction site, there may be a large number of batteries present in electric mobile machinery and storage systems. As such, it is important to think about the organisation of the parking and building site with regard to steps to be taken by the fire service to control and mitigate an incident and to ensure that sufficient distance is maintained. An unknown factor is the impact of a battery fire on the structure of the building under construction; this should be considered in the building safety plan.

3.5 Incident management

As with EVs in the logistics sector, the incident management procedures also apply to electric mobile machinery in construction, but the standard salvaging procedures do not (Section 2.5): the dimensions of electric mobile machinery are often too large for the immersion and salvage container. Generally speaking, the accessibility of construction sites in the event of an incident is addressed in building regulations, but as far as DNV is aware, there are no specific regulations for the use of electrical mobile machinery. It is important that the fire service has sufficient space to access the electric mobile machinery and that there is sufficient water available.

3.5.1 Existing research

DNV has not found any additional existing research that applies specifically to electric mobile machinery. According to those interviewed from the sector, it is very rare for a shovel or crane, for example, to catch fire as there is little combustible material present. There are very few fire incidents involving conventional mobile machinery in the construction sector.

3.5.2 Laws and regulations, standards and safety requirements

There are no additional requirements that apply specifically to electric mobile machinery.

3.5.3 Risks

3.5.3.1 Location of battery packs

There is no standard location for the battery pack in electric mobile construction machinery. The location is generally determined by practical considerations. In the case of a crane, for example, the mechanical balance partly determines the location of the battery pack. This means that in the event of an incident, emergency responders do not always know where the batteries are and, therefore, cannot quickly and easily secure the electric mobile machinery. Even if the location of the battery pack is known, depending on the location it may be difficult to take preventive cooling and extinguishing measures, and sustained cooling or immersion may be difficult. This can lead to unsafe situations; for example, the fire may spread to an adjacent object, and reignition may occur.

We that a rescue sheet [38] be made compulsory for each type of electric mobile machinery (similar to those required by EURO-NCAP for passenger electric vehicles [45]), which also indicates the locations of battery packs and appropriate actions to be taken in order to disconnect the electric mobile machinery from the power supply.

3.5.3.2 Safety of operators

A specific concern regarding electric mobile machinery is that they sometimes have open cabins. In this scenario, it is important that the machine can be stopped easily and that the safety of the operator can be ensured (able to escape before the (large) flames of a rapidly developing battery fire reach the cabin). This is unlike a diesel fire because the battery pack might be located just underneath the cabin.

3.5.3.3 Vehicle type and identification

Vehicles on the road must have a type approval, so that it is always possible to check whether a vehicle contains batteries using the registration plate. EURO-NCAP also requires a risk card (rescue sheet [38]) (currently only a requirement for passenger cars), which details, among other things, how the vehicle can be secured. However, electric mobile machines that are not driven on public roads do not have a registration plate, and so cannot be easily identified. A possible solution would be to facilitate identification using QR codes.

It is recommended that the use of risk cards also be made compulsory for electrical mobile machinery and that, if necessary, these machines also be included in commercial crash recovery databases (e.g., the Moditech database), so that emergency responders have digital technical information on the relevant electrical mobile machinery.

3.5.3.4 Incident location

Construction sites can sometimes be in remote locations without electricity or water. It is important that protocols are drawn up on how to respond to incidents in such locations or that additional regulations are formulated with which construction sites must comply. Preferably, these protocols should be included in the National Guidelines on Construction and Demolition Safety (*Landelijke richtlijn Bouw- en Sloopveiligheid*) published by the Netherlands Association for Building and Housing Control (*Vereniging Bouw- en Woningtoezicht Nederland*) (VBWTN) [70].

3.5.3.5 ATEX environment

A construction site can potentially be an ATEX (ATmosphere EXplosible) environment. If there is a risk of explosion, the ATEX 114 directive must be complied with (Directive 2014/34/EU [72]). The regulations for electric mobile machinery are no different than for petrol or diesel vehicles in an ATEX environment. Petrol vehicles have spark plugs, which is problematic in explosive atmospheres. Diesel vehicles do not have this problem. The risks associated with electric vehicles and mobile machinery in ATEX environments are even less known and have not been fully researched. The first electric ATEX vehicles are already available on the market (e.g., Alké [73], suitable for ATEX Zone 2).

3.6 Enclosed spaces

3.6.1 Existing research

DNV has not found any existing research that applies specifically to electric mobile machinery.

3.6.2 Laws and regulations, standards and safety requirements

There are no specific regulations, standards and requirements for electrical mobile machinery in enclosed spaces.

3.6.3 Risks

DNV has not identified any additional risks to those already described in Section 2.6.

3.7 Charging infrastructure

Charging on construction sites presents a number of challenges, the main one being the electricity supply. The charging infrastructure must be connected to the on-site installation that temporarily supplies the construction site with electricity. The on-site installation may be put under heavy load as soon as the electric mobile machinery is connected for charging. The available grid connection capacity on a construction site may be limited; this is the case, for example, in residential and non-residential construction. In civil engineering, there is even less certainty regarding the presence of a grid connection. This limitation in grid capacity may impede the rollout of electric machinery but is not a safety issue.

The availability of a standardised charging infrastructure itself is also a point of concern. Compared to the logistics sector, charging stations are not already available on the construction site; they must be connected temporarily. In many construction projects, the building shell is built first before work starts on the electrics. If charging is to be carried out on construction sites from day one, this order needs to be partially reversed. Improvised solutions, such as mobile boxes, tangled cables and overloading must be avoided by adopting a standard approach to integrating charging infrastructure on the construction site. It is important that approved cables and charging stations are used that function according to the existing EV standards. The first OEMs on the market (e.g., Volvo) are currently opting to supply charging stations along with the machines.

Both challenges can be solved by applying mobile charging infrastructure in combination with a battery container. This makes it possible to connect a machine to a standard charging station using an approved cable that can provide sufficient capacity during the day. Breytner is currently using mobile charging infrastructure as part of a pilot project for charging electric mobile machinery on construction sites [74]. The charging station is placed in a skid (open container frame) to ensure its protection and to make it easy to move after construction is completed. The mobile battery and charging station can be transported to the next construction site by e-truck.

Local solutions must be sought for situations away from the construction site. In some cases, public charging infrastructure in the neighbourhood is used. The NAL is currently developing a set of guidelines for these situations, which will include relevant safety aspects such as inspection and the locking of plugs and agreements with the CPO. If no charging solution is available, this may mean that an electric mobile machine has to be moved to another location to be recharged overnight.

In intralogistics[9], charging infrastructure has already been used for some time to charge lead batteries in particular, and now also Li-ion batteries, for example for forklift trucks. These are charged at so-called battery charging stations. Experience has shown that the way in which the charging infrastructure is used is extremely important (e.g., charging cables must be hung up correctly).

3.7.1 Existing research

DNV has not been able to find any existing research that focuses specifically on charging infrastructure for the construction sector.

3.7.2 Laws and regulations, standards and safety requirements

There are currently no specific regulations, standards or safety requirements for charging infrastructure in the construction sector. The expectation is that additional standards and rules will be introduced specifically for mobile charging solutions. Since charging in intralogistics has been taking place for decades, there are clear guidelines for charging in this sector. For example, there are requirements for good ventilation and a ban on smoking and open flames [75].

[9] Logistics of goods and materials on an industrial estate and in commercial buildings.

3.7.3 Risks

A construction site may not have adequate facilities, such as sufficient grid capacity and a standardised charging infrastructure. In this case, there is a potential risk that existing electrical infrastructure (e.g., site huts and adapter boxes) that has not been developed according to the appropriate standards (IEC 61851 and IEC 62196) is used for charging electric mobile machinery, ultimately resulting in overloaded cables or short circuits.

In the construction industry, there is also an increased risk of collisions involving the charging infrastructure (see 2.7.3).

It is recommended to use the existing regulations for battery charging stations in intralogistics as a starting point for regulations for charging on (and perhaps also in the vicinity of) construction sites.

3.8 Noise and absence thereof

3.8.1 Existing research

DNV has not found any existing research that applies specifically to electric mobile machinery.

3.8.2 Laws and regulations, standards and safety requirements

EU legislation for an AVAS only applies to vehicles with four or more wheels in the M and N category. Mobile machinery does not fall into this category [76] and is, therefore, not required to have an acoustic alerting system. Current mobile machinery, both conventional and electric, emits a signal (beep) when reversing.

3.8.3 Risks

As is the case for EVs on public roads, a lack of noise while driving could pose an increased risk to operators, drivers and individuals on the construction site (see 2.8). However, there are several key differences compared to public roads. Electric mobile machinery in construction is generally used on cordoned-off sites with large equipment, and the operators, drivers and individuals present are already more aware of the risk of collision than road users on public roads. In addition, electric mobile machinery operates at low speed. There is also often a lot of noise in the surrounding area. It is entirely possible that, in general, electric mobile machinery can help to reduce this danger by contributing to a quieter construction site where people are able to pay more attention. It also improves the intelligibility of workers on the construction site, which also increases safety.

3.9 Other safety aspects: behaviour and processes

Processes for electric mobile machinery are also under development in the construction sector. The challenge is that there are many different types of machines, which sometimes makes it difficult to draw up uniform guidelines and to effectively structure the processes and checklists for electrical mobile machinery in the construction sector. For example, BMWT has not yet adapted all inspection forms to accommodate electric mobile machinery.

The main risks are situated in the intermediate phase involving the retrofitting of electric mobile machinery, as the BMWT inspection requirements have not yet been adapted for this or are unclear or ignored.

In terms of behaviour, the biggest challenge in the construction sector is that most of the workers are mechanically trained. This means that they have little awareness of the potential risks of working with electrical engineering equipment and battery packs.

3.9.1 Existing research

Lessons learned from the intralogistics sector should be incorporated into practical implementation in the construction sector. Safety scans carried out by BMWT reveal that there is almost always something wrong with the battery charging stations: cables are not tidied up and stored away neatly, and there is a lack of compliance with regulations concerning personal protective equipment.

3.9.2 Laws and regulations, standards and safety requirements

Working conditions legislation and regulations state that work equipment must be in good condition, which means that a commissioning inspection (Working Conditions Decree, Chapter 7, Section 2, Article 7.4a, paragraph 1) as well as compulsory and frequent regular inspections (Working Conditions Decree, Chapter 7, Section 2, Article 7.4a, paragraph 3) are required. The safest minimum number of inspections is considered to be once a year. Electrically powered equipment is not expected to exhibit as much wear and tear. It is also compulsory to carry out a risk inventory and evaluation (RI&E) (see the Working Conditions Act, Article 5). The National Guidelines on Construction and Demolition Safety (*Landelijke richtlijn Bouw- en Sloopveiligheid*) includes recommendations on the step-by-step plan for the risk analysis and on the hazards to be assessed [70]. However, it does not mention hazards related to electrical mobile machinery. It is recommended that these guidelines be updated with regard to electric mobile machinery.

3.9.3 Risks

3.9.3.1 Training

When using safety checklists, the person in charge must have a thorough understanding of the points for attention and what to look out for. The same applies to other personnel on the construction site. Once workers are aware of the potential risks and understand why certain safety protocols need to be followed, it is much more likely that they will actually be followed. Construction workers tend to be trained mechanics and mechanical engineers, and there is limited electrical engineering expertise on the construction site. Consequently, they do not always appreciate the need to follow processes and working methods that have been designed to ensure safety, and which often require a little more effort. DNV therefore recommends that all construction site personnel who work with electric mobile machinery and vehicles receive training on the associated risks and the related background information.

3.9.3.2 Solution-oriented mindset

Construction workers are often pragmatic and innovative. At times, problems are solved in ways that are unconventional, unexpected and/or not in line with regulations. An example of such a situation is when outlets are required for charging electric mobile machinery. When risks are insufficiently identified and mitigated, unsafe situations arise. However, the level of safety awareness in the sector is generally high and workers are used to dealing with (known) risks. DNV recommends that everyone on a construction site receive training on how to recognise these emerging battery-related risks, in order to raise awareness of how to work safely. It is also recommended to appoint a supervisor on the construction site who is responsible for the general monitoring of the charging of (the batteries for) all electric mobile machinery and vehicles.

3.9.3.3 Knowledge sharing

It is important to regularly update processes, checklists and working methods in line with the latest insights from the sector and in response to any incidents and near misses. If necessary, instructions must be updated or new or additional instructions must be written. This will mean that general handbooks such as the National Guidelines on Construction and Demolition Safety (*Landelijke richtlijn Bouw- en Sloopveiligheid*) will also need to be updated with regard to electrical machinery and vehicles. This will also contribute towards the sharing of knowledge on electrical safety within the sector.

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions – general

In the logistics and construction sectors, relatively low numbers of electric vehicles and mobile machinery are currently in use, including both new vehicles and retrofitted/mounted vehicles (or machines). This study broadly suggests that the safety risks (probability times impact) associated with these electric vehicles and mobile machinery are, for now, limited, in both absolute and relative terms compared to conventional vehicles and mobile machinery. Although some incidents may have a major impact, especially if mitigation is inadequate, the likelihood of this happening is limited, and due to the low numbers of vehicles and mobile machinery currently in use, incidents will still be rare. However, it is recommended that efforts be made now to address the most serious safety risks identified, in view of the expected substantial growth of electric vehicles and mobile machinery in logistics and construction in the years to come; this growth will ultimately lead to these risks materialising. It is also prudent to monitor this growth and the development of (numbers of) incidents and safety risks so that, where necessary, adjustments can be made in good time.

Risks relating to charging infrastructure, vehicle safety and noise are estimated to be low. The biggest risks are associated with incident management and behaviour. Key recommendations stemming from this study are that incidents should be investigated, lessons learned should be shared (e.g., by a branch organisation such as TLN and BMWT) and a wide group of users should be informed about risks and mitigation.

Safety regulations for passenger cars have generally been effectively applied to electric vehicles and mobile machinery but have not yet been fully implemented in inspection and maintenance procedures for large electric vehicles and mobile machinery in logistics and construction.

The following sections provide a review of the risks and knowledge gaps identified in this study for each sector and safety topic, as well as the corresponding recommendations.

4.2 Conclusions – logistics

There is very little existing research that specifically addresses the safety of the logistics EVs that fall within the scope of this study. Although OEMs do carry out their own research into vehicle safety and electrical safety of the drivetrain, among other things, this research is not made public.

As for legislation and regulations, the following can be said:

- Existing EV regulations apply. These are general in nature and, therefore, also apply to logistics EVs. Examples include the 1994 Road Traffic Act (*Wegenverkeerswet*) and the type approval issued by the RDW. European requirements for road traffic (which the RDW follows) also specify requirements for the safety of electric drivetrains and batteries.
- With regard to electric vehicle safety, there are IEC standards that can also be used for EVs in logistics and construction. No specific standards for EVs in these sectors are expected to be published in the next three to five years. However, standards are being developed for high-capacity charging, which is particularly relevant for logistics EVs.
- NEN 9140 sets out requirements for documentation, work procedures, training requirements and responsibilities for working safely with EVs. This standard also applies to EVs in logistics and construction. Parties (maintenance companies in particular) are working on, or must start working on, implementing this standard in their work processes.
- There are clear rules and standards for electric charging infrastructure. However, there are no rules that require regular safety inspections and maintenance of these charging infrastructures, despite this being necessary to

maintain their technical integrity and safety. Public charging infrastructure is usually inspected annually by providers, so in practice this takes place without there being any legal obligation to do so[10].

Risks and knowledge gaps for each safety aspect are listed in Table 4-1.

Table 4-1 Risks and knowledge gaps regarding EVs in logistics

Topic	Risks	Risk assessment [11]	Knowledge gaps
Vehicle safety	Retrofitted vehicles with a one-off type approval may not have been adequately validated in terms of the battery pack and electric drivetrain[12]. In addition, the presence of extra batteries in the body, which do not fall within the scope of the type approval, can pose safety risks.	Medium	
Visible and invisible battery damage	It is unclear whether a battery is still safe following a (minor) incident/collision.	Low	Determination of whether a battery pack is damaged, based on BMS data, physical characteristics or measurements.
Fire safety	Since EV fires can be much more intense (hotter) for a short period of time and are more difficult to extinguish, there is an increased risk of the fire spreading to nearby vehicles, e.g., in a depot. An (intense) EV fire may have a greater impact on structural safety (tunnel, garage, etc.).	Medium	Determination of fire behaviour (burning time, intensity, progress), depending on vehicle type and location of batteries. Determination of the impact of (intense) fires on structural safety.
Incident management	There are currently no solutions for securing burnt e-trucks. Knowledge sharing is limited due to the reluctance of manufacturers and a fragmented regional approach. The variety of vehicle brands and types impedes the acquisition of knowledge. Information about trucks recorded in the information systems used by emergency services is incomplete.	High	Alternative methods of extinguishing and salvaging e-trucks (instead of immersion containers).

[10] The NEN 1010 installation standard does, however, include guidelines for regular inspection: using the provided decision tree results in an inspection interval of between one and five years. Suppliers and operators of charging stations follow a one-year interval, with visual checks often being carried out every month.

[11] **This is a qualitative assessment (probability times impact) for the risks identified per topic. Levels used: low, medium and high. High risk refers to the expectation that the risks involved will lead to low-impact incidents within months, and/or to high-impact incidents within a few years.**

[12] For the inspection, the RDW relies on the test certificates issued by the battery and drivetrain manufacturers. If the tests are carried out by reputable institutions such as TÜV, it can be assumed that no additional risks are involved. However, the RDW's requirements regarding the validity and level of detail of the test certification are unknown.

Topic	Risks	Risk assessment [11]	Knowledge gaps
	The procedure that is to be followed in the event an EV ends up in (a body of) water is not suitable for e-trucks.	Low	
Enclosed spaces	No specific fire safety requirements for EVs and charging infrastructure in enclosed spaces. Possibly insufficient fire extinguishing water available.	Medium	Method for salvaging EVs in enclosed spaces (tunnel, garage).
Charging infrastructure	Regular safety inspections and maintenance do take place, but this is not mandatory. Higher risk of collision with charging infrastructure. Higher risk of overloading the installation to which the charging infrastructure is connected (e.g., cable dimensioning).	Low	
Noise and absence thereof	EVs before July 2021: increased traffic risk due to lack of noise at low speeds (not applicable to newer EVs with mandatory AVAS).	Low	Determination of best way to mitigate this risk, e.g., AVAS, different acoustic alerting system, driver training, etc.
Behaviour and processes	Little knowledge of and experience with EV safety (especially in smaller companies), therefore risk of, for example, unskilled use, repair and incident management. NEN 9140 has not yet been properly implemented at companies that work with e-trucks, which can lead to unsafe situations.	High	
	In the event of incorrect actions (loading), the safe (permitted) load weight may be exceeded.	Low	

4.3 Conclusions – construction

There also appears to be virtually no publicly available literature on the safety of electric mobile machinery in the construction sector, most likely because there is still very little experience with it. There seem to be no specific regulations for electric mobile machinery, for example with regard to stability, battery protection, charging infrastructure, etc. Obviously, however, general legislation and regulations do apply, such as working conditions legislation, NEN 9140 and NEN 1010. Risks and knowledge gaps for each safety aspect are listed in Table 4-2.

Table 4-2 Risks and knowledge gaps regarding electric mobile machinery in construction

Topic	Risks	Risk assessment[11]	Knowledge gaps
Vehicle safety	Retrofitted mobile machinery and mobile machinery with additional batteries may have different safety characteristics (and, therefore, require different mitigation measures) than those anticipated in the original design, and may not be adequately tested and certified in this respect. Operators of electric mobile machinery and other workers may not be sufficiently familiar with the differences compared to ICE vehicles, such as: stability, increased acceleration, risk of collision.	Medium	General test protocol for each type of retrofitted mobile machine with clear validation requirements for the battery and drivetrain.
Visible and invisible battery damage	Risk of collision, fall or impact is greater in the construction sector than in other usage situations. It is unclear whether a battery is still safe following such an incident. OEMs account for this in the design; in the case of retrofits, this issue may not be adequately taken into account, and there seems to be a lack of specific regulations.	Medium	Determination of whether a battery pack is damaged, based on BMS data, physical characteristics or measurements.
Fire safety	Since EV fires can be much more intense (hotter) for a short period of time and more difficult to extinguish, there is an increased risk of the fire spreading to nearby mobile machinery, e.g., in depots. Possible impact of (intense) fire involving an electric mobile machine on structural safety (of buildings under construction and other structures on the construction site).	Medium	Determination of fire behaviour (burning time, intensity, progress), depending on the type of electric mobile machinery and location of the batteries. Determination of the impact of fires involving electric mobile vehicles on the structural safety of buildings under construction and other structures on the construction site.

Topic	Risks	Risk assessment[11]	Knowledge gaps
Incident management	There are no solutions for securing large burnt electric mobile machinery. Information about electric mobile machinery recorded in systems used by the emergency services is incomplete.	High	Alternative methods of extinguishing and salvaging (instead of immersion containers). Risks of electric mobile machinery in ATEX environment and related solutions.
Enclosed spaces		Low	Method for salvaging EVs in enclosed spaces.
Charging infrastructure	Unsafe charging infrastructure (temporary or otherwise) may possibly be used, as there is no standard infrastructure available or there is only a very limited supply of electricity at the start of construction.	Medium	
Noise and absence thereof	The lack of noise produced by electric mobile machinery and vehicles when in operation may pose a risk to other mobile machinery, vehicles and individuals on the construction site (but may also increase safety). AVAS mitigates this risk but is not mandatory for machines that are not intended for use on public roads and for vehicles manufactured before July 2021.	Low	Risk assessment of the lack of noise without AVAS (Is this even a risk at all? If so, is it significant in comparison to other risks on the construction site, given the level of ambient noise already present?) If relevant: determination of best way to mitigate this risk, e.g., AVAS, different acoustic alerting system, operator/driver training, etc.
Behaviour and processes	Little knowledge of and experience with electric mobile machinery (especially in smaller companies), therefore risk of, for example, unskilled use, repair and incident management. These risks are amplified in the construction sector due to the solution-oriented mindset and the generally low level of electrical engineering expertise. Sharing knowledge can reduce these risks. At present, knowledge of and knowledge sharing regarding electric mobile machinery in the construction sector is still very limited.	High	

4.4 Recommendations

Drawing on the observations made in chapters 2 and 3 of this study, DNV has compiled the following recommendations, listed in the table below. Generally, these recommendations apply to both the logistics and the construction sectors, unless otherwise indicated. The recommendations are categorised and numbered, and for each recommendation a suggestion is given as to which party or parties could assume responsibility for the issue. Recommendations that can and should have a high impact in the short term have been indicated as 'priority'.

Table 4-3. Recommendations for safe electric driving in logistics and construction

Category	#	Recommendation	Party
Battery	1	Develop methods for detecting (invisible, internal) battery damage in EVs and electric mobile machinery. The BMS with internal sensors and data analysis can play a role here.	OEMs (if available to third parties)
	2	Pay extra attention to the inspection of the battery pack in electric vehicles and mobile machinery that have been retrofitted or have mounted elements. The inspection agency will have to check that the required design requirements have been followed and that tests and validations have been carried out sufficiently and correctly.	Government. ***Priority***
Vehicle safety and incident management	3	Research how fires involving large EVs and electric mobile machinery develop as well as the safe distances required, focusing in particular on enclosed spaces such as tunnels and garages.	Government, fire service, IFV, universities
	4	Review the safe spatial organisation of, and draw up regulations for, logistical areas and construction sites where EVs and electrical mobile machinery are parked and charged, especially with regard to safe distances between vehicles/mobile machinery, in particular during charging, the availability of (fire extinguishing) water, etc.	Government, standards committees
	5	Update procedure that is to be followed in the event an EV ends up in (a body of) water with regard to large EVs.	Emergency services
	6	Update the information systems used by emergency services (rescue sheets) with information on large EVs and electric mobile machinery, including the location of the battery pack, adequate positions for de-energising the vehicle, and possibly the type of battery (e.g., Li-ion NMC), capacity and power. Possibly affix information to the vehicle itself (e.g., a QR code).	OEMs (information), government (mandatory updating of information)
	7	Develop a method for the long-term securing of large burnt EVs.	Emergency services ***Priority***
	8	Determine the impact of EV fires on the structural safety a) For fires involving logistics EVs: of, for example, tunnels and depots/garages	IFV, TNO, universities

Category	#	Recommendation	Party
		b) For fires involving construction EVs: of buildings under construction and other structures on the construction site	
	9	Review and, if necessary, update building regulations with regard to the accessibility of construction sites and the possibilities of extinguishing fires involving electric construction vehicles, especially on sites without electricity and water.	Government
	10	Determine the risks of EVs and electric mobile machinery in ATEX environments and find appropriate solutions.	Research institutes, standards committees
Behaviour and processes	11	Improve the accumulation of knowledge by implementing uniform protocols, a national approach/training and sharing knowledge of incidents and near misses within the sector.	Government, branch organisations ***Priority***
	12	Ensure that companies that work on e-trucks and electric construction vehicles implement NEN 9140 properly.	Branch organisations
	13	Train operators of electric mobile machinery in the following aspects: stability differences, greater acceleration.	OEMs, branch organisations, end users
	14	More comprehensive training for employees in both logistics and construction regarding EVs and electric mobile machinery and their batteries: handling, recognising risks, what to do in the event of an incident. Topics include collisions, falling of loads, handling (exchangeable) batteries, preventing and dealing with damage to batteries, etc. Relevant work regulations must be revised.	OEMs, branch organisations, end users ***Priority***
	15	Appoint a supervisor for the charging of electric mobile machinery and EVs on every construction site.	Construction companies
Noise	16	Assess the risks of the lack of noise (for certain EVs and electric mobile machinery): Is this even a risk at all on construction sites? If so, is it significant in comparison to other risks on site, given the level of ambient noise already present? If yes for construction, and in any case for logistics: determine the best way to mitigate this risk, e.g.: AVAS, different acoustic alerting system, operator/driver training, etc.	Research institutes
Charging infrastructure	17	Draw up procedures for safe (temporary) charging infrastructure on the construction site.	Branch organisations

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APPENDIX A
Abbreviations

Table A-1 List of abbreviations

BMS	Battery Management System
CCS	Combined Charging System
EV	Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
HPC	High-Power Charging
ICE	Internal Combustion Engine
LFP	Lithium Iron Phosphate
Li-ion	Lithium-ion
MCS	Megawatt Charging System
MES	Multi-Energy Station
MMS	Motor Management Systeem
NMC	Nickel Manganese Cobalt
OEM	Original Equipment Manufacturer
PHEV	Plug-in Hybrid Electric Vehicle

APPENDIX B
Supervisory group and interviewees

Composition supervisory group

Table B-1 Supervisory board of this study

Organisation	Contact person
Netherlands Enterprise Agency	Sipke Castelein
Netherlands Enterprise Agency	Suzan Reitsma
Netherlands Enterprise Agency	Bregje van Keulen
National Charging Infrastructure Agenda – Logistics; APPM	Mark van Kerkhof
ElaadNL	Paul Broos
Netherlands Knowledge Platform for Public Charging Infrastructure of Electric Vehicles	Robert van den Hoed
Directorate-General for Public Works and Water Management (*Rijkswaterstaat*)	Nico van den Berg
Ministry of Infrastructure and Water Management	Paul Penders
Netherlands Institute for Public Safety	Johan van der Graaf

Interviewed parties

Table B-2 List of interviewed stakeholders

Organisation	Contact person	Status
BMWT	Albert Lusseveld	Interviewed
Breytner	Marie-Jose Baartmans Jeroen Baartmans	Interviewed
Heijmans	Stefan Daamen	Interviewed
Albert Heijn	Alannah Hoenderdaal	Interviewed
Urban Mobility Systems (UMS)	Lars Kool	Interviewed
Service Machinery Trucks (SMT)	Ben Möhlmann	Interviewed
Netherlands Institute for Public Safety	Tom Hessels	Interviewed
Volvo	Wijnand van den Brink John Timmers	Interviewed
RAI Association	Wout Benning	Interviewed
DHL	Wout Zellenrath	Interviewed
Municipality of Utrecht	Matthijs Kok	Interviewed
Safety region	Sasbout Koning	Interviewed
BOVAG	Aad Verkade	Interviewed

About DNV

DNV is the independent expert in risk management and assurance, operating in more than 100 countries. Through its broad experience and deep expertise DNV advances safety and sustainable performance, sets industry benchmarks, and inspires and invents solutions.

Whether assessing a new ship design, optimizing the performance of a wind farm, analyzing sensor data from a gas pipeline or certifying a food company's supply chain, DNV enables its customers and their stakeholders to make critical decisions with confidence.

Driven by its purpose, to safeguard life, property, and the environment, DNV helps tackle the challenges and global transformations facing its customers and the world today and is a trusted voice for many of the world's most successful and forward-thinking companies.