SUSTAINABLE TRANSPORT FORUM

FIRE SAFETY – ELECTRIC VEHICLES AND CHARGING INFRASTRUCTURE

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GUIDANCE ON FIRE SAFETY FOR ELECTRIC VEHICLES PARKED AND CHARGING INFRASTRUCTURE IN COVERED PARKING SPACES

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Executive Summary

As battery electric vehicles (BEVs) continue to grow in number on European roads, their integration into urban infrastructure—particularly in covered parking facilities—has become a key focus for regulatory and safety considerations. Recognizing this, the European Commission's Sustainable Transport Forum (STF) Task Force 6 has developed comprehensive guidelines aimed at identifying and mitigating fire risks, as well as ensuring the safe installation of recharging infrastructure in covered parking areas. This guidance, which provides an overview of technical, organizational, structural, and preventive fire safety measures, is intended for public authorities and other stakeholders involved in fire safety in covered parking facilities. These include parking operators, designers, risk assessors, fire service organizations, and original equipment manufacturers (OEMs).

Despite initial concerns, existing studies show that BEVs do not present a higher fire risk than internal combustion engine vehicles (ICEVs). However, fires involving lithium-ion batteries present unique challenges, such as thermal runaway, jet fires, and vapor cloud explosions. Additionally, fire safety issues may arise from the condition and reliability of recharging infrastructure.

The guidance outlines several fire safety strategies aimed at reducing fire risks in covered parking facilities, which can be grouped into five key areas:

1. **Prevention**: Recommends fire risk assessments for both new and existing parking facilities.
2. **Detection**: Suggests the installation of advanced fire detection systems that can quickly identify fires involving BEVs.
3. **Evacuation**: Stresses the importance of designing clear evacuation routes and placing recharging points away from emergency exits to facilitate quick evacuations.
4. **Propagation Control**: Recommends using fire-resistant systems and compartmentalization in parking structures to prevent the spread of fire between vehicles.
5. **Firefighting**: Emphasizes the need for specialized firefighting equipment and techniques tailored to the unique risks posed by BEV fires.

In conclusion, these guidelines provide a crucial roadmap for addressing fire safety challenges in covered parking facilities where BEVs are present, while also supporting EU decarbonization goals. Hence, the guidance aims to contribute to a safer environment for the widespread adoption of BEVs.

1. Introduction

In recent years, the prevalence of electric vehicles (EVs) on European roads has surged remarkably, with light battery electric vehicles (BEVs) such as cars and vans leading this transformative trend. Globally, close to 14 million BEVs were sold in 2023, capturing a notable 18% market share, and all signs point to this momentum continuing strong.[1]

The European Commission's Fit for 55 package represents an ambitious climate agenda aiming to reduce road transport emissions to zero in the European Union (EU) by 2050. In line with this objective, several key legislations have been implemented or are in development to accelerate the widespread adoption of zero-emission vehicles across the EU. One landmark initiative is the EU's mandate requiring all new vehicles sold to be zero-emission by 2035. Additionally, the Alternative Fuels Infrastructure Regulation (AFIR) establishes minimum standards for deploying recharging stations, including those in publicly accessible covered parking areas such as shopping centres and public parking lots. Further advancing this agenda, the recast Energy Performance of Buildings Directive (EPBD) was adopted[2] in May 2024.

The revised EPBD is strategically aligned with decarbonisation goals, emphasising the critical role of the built environment in facilitating the transition to zero-emission vehicles. The Directive focuses on expanding infrastructure to support BEV adoption by promoting pre-cabling and the installation of recharging points in residential and non-residential buildings throughout the EU. By seamlessly integrating EV infrastructure into building design, the Directive aims to improve charging convenience and accessibility, thereby fostering the transition to cleaner transportation and significantly contributing to the EU's broader decarbonisation objectives.

As electromobility becomes increasingly prevalent, European lawmakers have also recognised the need for harmonised fire safety measures in covered and underground parking spaces. In response, the European Commission has been asked in the revised EPBD for developing specific guidelines to address the fire safety of BEVs in such settings.

The deployment of recharging infrastructure—encompassing both normal and high-power recharging points in buildings and parking areas—is seen as vital for enabling citizens to charge their vehicles conveniently. Normal power recharging points, which make up the bulk of the infrastructure, provide consumers with affordable charging options. Several countries have also embraced the *'right-to-plug'* principle, granting tenants the ability to install recharging points in garages without undue interference from landlords or co-owners. This approach helps to

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[1] (IEA, 2023)

[2] (*Directive [EU] 2024/1275 of the European Parliament and of the Council of 24 April 2024 on the Energy Performance of Buildings [Recast]*, 2024)

streamline access to recharging infrastructure, further supporting the adoption of BEVs.

While the rapid growth of BEVs and recharging infrastructure raises concerns about increased fire risks in covered parking areas, early studies suggest that BEVs are actually less prone to fires compared to internal combustion engine vehicles (ICEVs). Nevertheless, it is important for public authorities, parking operators, insurers, firefighters, and citizens to address potential risks associated with BEV deployment and the installation of recharging points. Factors such as evolving vehicle sizes, new materials, and advancements in powertrain technology demand continuous attention, especially as legislative frameworks and building codes often lag behind these changes, particularly in existing buildings and parking facilities.

1.1. Objectives and Scope

This document, prepared by the Sustainable Transport Forum (STF) under the leadership of the European Commission and supported by a group of European organisations, highlights key challenges and best practices related to the deployment of BEVs in covered parking areas. It also provides a set of recommendations for public authorities and private stakeholders to facilitate the adoption of BEVs in covered parking lots.

The report has three main objectives:

- **Identify** existing and upcoming legislation relevant to the deployment of BEVs and recharging infrastructure in covered parking areas.
- **Examine** challenges and existing practices concerning fire safety in covered parking areas in relation to the deployment of electromobility.
- **Provide** recommendations for public authorities and private stakeholders to enhance fire safety measures in covered parking areas.

This guidance document is designed to assist local public authorities in creating a fire safety framework for BEVs in covered parking areas. It also serves as a resource for parking lot operators, designers, risk assessors, original equipment manufacturers (OEMs), and property owners involved in installing BEV recharging stations in both new and existing covered parking facilities. The overarching goal is to promote the safe and widespread integration of BEVs and recharging infrastructure in these spaces.

The guidance specifically focuses on **category M1[3] BEVs** intended for passenger transport, such as cars and vans equipped with lithium-ion batteries, which are currently the most prevalent type. It exclusively addresses existing lithium-ion battery technologies available on the market today.

Within the broader context of electromobility, a key distinction is drawn between BEVs and electric micromobility devices, such as e-scooters and e-bikes. BEVs—comprising cars and vans—typically pose a lower fire safety risk compared to micromobility vehicles. This is due to the advanced engineering of BEV batteries, which are larger and more securely integrated into the vehicle structure.

This guidance focuses exclusively on BEVs, categorised under the United Nations Economic Commission for Europe (UNECE) M1, to thoroughly analyse and address the specific fire safety challenges associated with this group, acknowledging their relatively lower risk profile compared to other electromobility solutions.

1.2. Debunking Myths

The most common causes of fires in BEVs include constantly powered circuits and higher current or amperage, which can lead to overheating of components such as fuses, connectors, and wiring harnesses.[4] Fire hazards associated with lithium-ion traction batteries often involve potential short circuits due to loose parts, faulty electrodes, corrosion, or flammable materials near the batteries.[5] Because of the fundamental differences between ICEVs and BEVs, firefighting strategies for BEV fires may differ from those for ICEV fires, particularly if the battery becomes involved.

Numerous reports from scientists and fire safety organisations emphasise that fires in BEVs are relatively uncommon[6], occurring less frequently than in ICEVs, which are reported to burn 20 times more often than BEVs, according to the Swedish Civil Contingencies Agency (MSB)[7]. The BEV fleet is still relatively young compared to that of ICEVs, so as BEVs age, there may be an increase in fire incidents, particularly among vehicles owned by individuals who neglect proper maintenance. In 2022, the MSB reported a total of 106 fires in various types of electrified modes of transport in Sweden.[8] Of these, 38 occurred in electric scooters and 20 in electric bicycles, while 23 were in EVs—representing just 0.004% of Sweden's 611,000 BEVs.[9] In contrast, 3,400 fires were reported

[3] (*Classification and Definition of Vehicles | UNECE)*
[4] (Troitzsch, 2022)
[5] (Troitzsch)
[6] (*EV Battery Fire Data*)
[7] (*Bränder I Eltransportmedel under 2022*)
[8] ("Myths and Facts about Fires in Battery Electric Vehicles", 2022)
[9] ("Myths and Facts about Fires in Battery Electric Vehicles", 2022)

in Sweden's 4.4 million petrol and diesel cars during the same period, equating to 0.08% of the fossil fuel vehicle fleet.[10]

Similarly, in Norway, data from the reporting system of the Norwegian Directorate for Civil Protection (DSB) recorded 998 fires between 2016 and 2018, of which 109 were attributed to electrical equipment, and 65 originated in vehicles—only two of these were in electric cars.[11] In the Netherlands in 2023, there were nearly half a million BEVs.[12] That year, just 181 fire incidents involved all types of electric vehicles (including BEVs, light-duty vehicles, and heavy-duty vehicles), demonstrating the low frequency of BEV-related fires.[13]

Notably, fires in electric vehicles appear to be decreasing. According to the MSB, the number of fires in electric cars has remained around 20 fires annually over the past three years, even though the number of EVs has nearly doubled in that time in Sweden.[14] This decline is likely due to improvements in fire-suppression designs in newer BEV models. Norway, which has the highest proportion of BEVs globally, reported that EVs account for just 2.7% of vehicle fires despite making up 17.3% of the passenger car fleet in 2020.[15] Data suggest that EV fires are less frequent than ICEV fires by a factor of 8 to 10.[16] Most fires in electric transportation devices (78.2%) involve scooters, kick-bikes, hoverboards, and electric bicycles or motorbikes, rather than cars.[17]

BEV fires are not significantly larger, more intense, or more dangerous than those in ICEVs.[18] Research conducted by RISE through the LASH FIRE project, which tested fire suppression systems on both ICEVs and EVs, concluded that EV fires do not pose greater challenges for fire control than ICEV fires when adhering to current international recommendations for drencher systems.[19] While EV fires share some similarities with ICEV fires, they also present unique risks that require specific attention.

The spread of BEV fires to nearby vehicles is no faster than that of ICEV fires. While lithium-ion batteries can produce jet flames that may spread fire, ICEVs typically carry large amounts of liquid fuel.[20] A leaking fuel tank can cause a pool fire that spreads over several meters. Regarding the speed of fire propagation, the polymer fuel tank of an ICEV will ignite more quickly than the lithium-ion

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10 ("Myths and Facts about Fires in Battery Electric Vehicles")
11 ("Myths and Facts about Fires in Battery Electric Vehicles")
12 (Vanhaverbeke et al., 2024)
13 (*NIPV Annual Report 2023*, 2024)
14 ("Myths and Facts about Fires in Battery Electric Vehicles")
15 (Hynynen et al., 2023)
16 (Mohd & César Martín-Gómez, 2023)
17 (Hynynen et al.)
18 (Presentation by Olla Willstrand from RISE at the webinar on Safety aspects of EV manufacturing, use, maintenance, repair and disposal organised by ALBATTS on 3 May 2023)
19 (Hynynen et al.)
20 ("Myths and Facts about Fires in Battery Electric Vehicles")

battery of an EV when exposed to external heat.[21] However, according to the United States National Fire Protection Association (NFPA), extinguishing BEV and hybrid vehicle fires often takes longer than conventional car fires.[22]

A common misconception about BEV fires is that they burn at extremely high temperatures. In reality, the temperature of any fire depends on several factors, including the type of fuel, atmospheric pressure, ambient temperature, and oxygen levels. There is no evidence that BEV fires burn hotter than those in ICEVs.

Although recent studies suggest that BEVs do not carry a significantly higher fire risk than ICEVs, long-term statistical data remains limited. Insurers and researchers need more comprehensive data to better assess and mitigate these risks.

1.3. Definitions and Acronyms

Acronyms

- AC: Alternating current
- AFIR: Alternative Fuels Infrastructure Regulation
- AVERE: European Association for Electromobility
- BMS: Battery Management System
- CO: Carbon monoxide
- CO2: Carbon dioxide
- CTIF: International Association of Fire and Rescue Services
- DC: Direct current
- DSB: Norwegian Directorate for Civil Protection
- EFSN: European Fire Sprinkler Network
- EPBD: Energy Performance of Buildings Directive
- EU: European Union
- Euro NCAP: European New Car Assessment Programme
- EV: Electric vehicle
- EVSE: Electric vehicle supply equipment
- FEEDS: European Electrical Domestic Safety
- IC-CPD: In-Cable Control- and Protection Device
- ICEV: Internal combustion engine vehicle
- HCN: Hydrogen cyanide
- HF: Hydrogen fluoride
- IEC: International Electrotechnical Commission
- MSB: Swedish Civil Contingencies Agency
- NFPA: National Fire Protection Association in the United States of America

[21] ("Myths and Facts about Fires in Battery Electric Vehicles")
[22] (Willstrand et al., 2019)

- NIPV: Netherlands Institute for Public Safety
- OEM: Original equipment manufacturer
- SEI: Solid electrolyte interphase
- SOC: State of Charge
- STF: Sustainable Transport Forum
- UNECE: United Nations Economic Commission for Europe
- VCE: Vapor-cloud explosion
- VOC: Volatile Organic Compound

Definitions

- Battery Electric Vehicles (BEV): An electric vehicle that runs exclusively on the electric motor, with no secondary source of propulsion.[23]
- Category M1 vehicle: Vehicles used for the carriage of passengers and comprising not more than eight seats in addition to the driver's seat.[24]
- High Power Recharging Point: A recharging point with a power output of more than 22 kW for the transfer of electricity to an electric vehicle.[25]
- Normal Power Recharging Point: A recharging point with a power output less than or equal to 22 kW for the transfer of electricity to an electric vehicle.[26]

[23] *[Regulation (EU) 2023/1804 of the European Parliament and of the Council of 13 September 2023 on the Deployment of Alternative Fuels Infrastructure, and Repealing Directive 2014/94/EU*, Article 2(10), 2023]

[24] (*EU Classification of Vehicle Types* | *European Alternative Fuels Observatory*)

[25] *[Regulation (EU) 2023/1804 of the European Parliament and of the Council of 13 September 2023 on the Deployment of Alternative Fuels Infrastructure, and Repealing Directive 2014/94/EU*, Article 2(31), 2023]

[26] *[Regulation (EU) 2023/1804 of the European Parliament and of the Council of 13 September 2023 on the Deployment of Alternative Fuels Infrastructure, and Repealing Directive 2014/94/EU*, Article 2(37), 2023]

2. Overview of legislations and guidelines in place across Europe

2.1. Austria

OIB Guideline 2.2; Safety in case of fire in garages, roofed parking spaces, and multi-storey car parks

- **Type**: Guidelines issued by the Austrian Institute for Construction Technology (OIB). OIB acts as a coordination platform for the federal state for building products and building technology.
- **Scope of Application**: National level, providing comprehensive regulations for fire safety in parking areas, particularly focusing on electric vehicles (EVs) and their recharging points.

Structural Fire Protection

- **Fire Compartments**: The guideline does not specify the use of fire-resistant walls, doors, or gates for compartmentalisation. However, it recommends reducing fire risks if EVs cannot be easily removed in case of a fire.
- **Access for Removals of EVs**: No charge points allowed in car parks with car elevators to mitigate fire risks.

Technical Fire Protection

- **Isolation Switch to Cut Power Supply**: An isolation switch is required to cut the power supply in case of an emergency, ensuring that electrical systems can be quickly deactivated during a fire.

Preventive Fire Protection

- **Special Rules for Fast Charging**: Charging stations with power greater than 22kW are only permitted under specific conditions: single-floor car parks on street level with a maximum area of 250 sqm, in fire compartments with automatic extinguishers and 24/7 security centre notifications, or in fire compartments with fire alarm systems connected to a 24/7 security centre. These stations must also be positioned close to entry and exit points or on floors +1 or -1.

2.2. Belgium

Code of Good Practice - Fire Safety for Electric Vehicles in Parking Areas

- **Type**: Guidelines by Fire Forum, NGO striving to improve fire safety by stimulating dialogue, the dissemination of knowledge and information, and the promotion of quality and innovation.
- **Scope:** The Belgian guidelines are applicable at the national level. They provide specific regulations for the fire safety of electric vehicles (EVs) and their recharging points within parking areas across Belgium.

Structural Fire Protection

- **Fire Compartments**: Emphasises compartmentalisation with fire-resistant materials in parking areas. Specific guidelines for the construction and fire stability of parking lots, ensuring they remain structurally sound in the event of a fire.
- **EV Removal Access**: Requirements for ramps and access ways to facilitate the easy removal of EVs. In cases where access is through an elevator, a post-fire alternative must be provided.

Technical Fire Protection

- **Fire Extinguishing Systems**: Evaluations for sprinkler systems in parking lots, especially for existing structures, considering the size of the parking, the number of EVs, and the presence of recharging points.
- **Ventilation and Smoke Extraction**: Guidelines for effective smoke and heat extraction systems, with a focus on preventing explosive or toxic atmospheres. Recommendations for ventilation openings at each parking space equipped with a charging station.

Organisational Fire Protection

- **Risk Assessment and Emergency Planning**: Parking operators are required to conduct risk assessments and collaborate with firefighters for emergency planning. Post-fire, it is essential to check the stability of EV batteries before allowing vehicles to remain in the parking.

Preventive Fire Protection

- **Recharging Point Regulations**: Recommends avoiding Mode 1 and 2 recharging points due to safety concerns. Mode 4 charging stations require technical justification and local fire department approval.
- **Installation and Maintenance**: The installation of EV charging stations must comply with specific electrical regulations. Regular inspections and a logbook for initial and periodic inspections are advised.

2.3. Czechia

Fire Safety of Buildings – Electromobility - Guidelines from the Ministry of the Interior - General Directorate of the Fire Rescue Service of the Czech Republic, April 2021

Type: National guidelines addressing fire safety in relation to electric vehicles (EVs) and recharging points.

Scope of Application: National level with specific provisions for EVs and recharging points within parking structures.

Structural Fire Protection

- **Fire Compartments**: The guidelines recommend the installation of fire compartments with appropriate fire-resistant walls, doors, and gates. The guidelines emphasise ensuring structural stability in case of fire but do not mandate specific fire resistance ratings. It is necessary to take into account the specific design of the construction, evaluate specific risks and identify appropriate measures.

- **Access for Removals of EVs**: The guidelines suggest that parking spaces for charging EVs should have a minimum width equal to spaces for disabled persons, facilitating safe firefighting operations. Charging spaces are recommended only in solid floor areas, not in stackers or similar devices, to ensure firefighting access.

Technical Fire Protection

- **Fire Extinguishing Systems**: An Automatic Sprinkler System is recommended in fire zones with EV charging points.

- **Smoke and Heat Extraction**: Installation of a Smoke and Heat Exhaust System is recommended. In the case of modifications to existing buildings, a Smoke and Heat Exhaust System is recommended from 4 charging spots in one fire zone.

- **Fire Alarm Systems**: The installation of Electric Fire Alarm Systems is recommended in fire zones of collective garages. It is preferred to connect the Electric Fire Alarm System to the Centralised Protection Panel of the locally relevant Regional Fire Rescue Service.

Organisational Fire Protection

- **Safety Recommendations**: The guidelines suggest a Level IV Degree of Fire Safety for fire zones unless a higher level is required by national standards. The Fire Safety Solution should include a firefighting plan for transporting vehicles with batteries after a fire.

- **Risk Assessment and Emergency Planning**: As part of the assessment of firefighting options (and as a potential basis for the development of firefighting documentation), the Fire Safety Solution should include:

Assessment and description of how to transport a vehicle with a battery in a non-standard state (e.g., after a fire) from the collective garage area, considering the technical means available to the local Regional Fire Rescue Service to ensure vehicle transport.

Preventive Fire Protection

- **Location and Installation**: Parking spaces for charging EVs should be designed with at least 3.5 meters in width and should only be located in solid floor areas. Single and row garages are subject to existing fire safety standards without additional requirements for EV charging.

Decree No. 146/2024 Coll. on construction requirements

- **Type**: National Decree on Construction Requirements
- **Scope**: National level legislation focusing on construction requirements, with specific provisions related to electric vehicle (EV) recharging points.

Preventive Fire Protection

- **Type of EV Recharging Points**: The decree outlines various types of electric vehicle recharging points. Regular AC charging points must be equipped with at least a socket or a type 2 vehicle socket connection, while high-performance AC charging points require at least a type 2 socket outlet. High-performance direct current (DC) charging points must have a Combo 2 charging system socket connection. Publicly accessible AC charging points with an apparent power of less than 3.7 kVA, reserved for L-category electric vehicles, need to have either a type 3 A vehicle socket connection for mode 3 charging or a socket for charging modes 1 or 2. For publicly accessible AC charging points with an apparent power of more than 3.7 kVA, reserved for L-category electric vehicles, they must be equipped with at least a type 2 socket or vehicle connection.

2.4. France

Building code established by the order of June 25, 1980, further detailed by the order of May 9, 2006.

- **Type**: Building code by the French Ministry
- **Scope of Application**: National level, with explicit specifications related to electric vehicles and recharging points. This regulation concerns building open to the public.

Structural Fire Protection

- **Compartmentalisation**: Parking lots are divided into compartments not exceeding 3000 square meters, extendable to 6000 square meters with sprinkler systems. Compartment walls require a minimum fire-stop rating of one hour. Automated storage areas and partition walls are subject to stringent fire-resistance standards.
- **Access and Egress**: Regulations specify maximum walking distances to exits or staircases, with staircases either enclosed in fireproof walls or located outdoors.

Technical Fire Protection

- **Fire Suppression Systems**: Installation of automatic sprinkler systems is mandated for covered parking lots with more than two levels.
- **Smoke and Heat Extraction**: Mechanical extraction is required for most scenarios, with extraction rates detailed per vehicle and compartment size. Fire alarm systems and smoke detectors are essential for large-capacity parking lots.
- **Hydrants and Firefighting Measures**: Detailed provisions for hydrant installations and the presence of portable fire extinguishers at strategic locations.

Organisational Fire Protection

- **Safety Recommendations**: Prohibitions on combustible material storage, fuel addition, smoking, or open flames within the parking area.
- **Firefighters' Access and Water Supply**: Specifications for the installation of dry columns and hydrants to ensure adequate water supply for firefighting.

Preventive Fire Protection

- **Recharging Points**: Limits on the number of charging points per compartment and the total deliverable power. Specific conditions are outlined for the installation of fast charging points, emphasising the need for isolation and fire-resistant barriers.
- **Maintenance and Inspection**: Regular inspection schedules for electrical installations and recharging points, emphasising operational safety and compliance with national and international standards.

Fire Prevention Guide for Covered Parking Areas called “guide PS”

- **Type**: Guidelines by the Ministry of Interior
- **Scope of Application**: Specifically tailored to covered public parking lots accommodating more than 10 vehicles, with a focus on fire safety measures for EV recharging points.

Structural Fire Protection

- **Compartmentalisation and Materials**: The guidelines specify requirements for fire-resistant materials and compartmentalisation in parking structures to limit fire spread and damage.
- **Access and Evacuation**: Detailed provisions for access and evacuation routes, including emergency exits and signage, ensuring quick and safe egress during a fire incident.

Technical Fire Protection

- **Fire Detection and Suppression Systems**: Recommendations for installing advanced fire detection systems and suppression equipment, particularly in areas housing EV charging stations.
- **Ventilation and Smoke Control**: Emphasises the importance of adequate ventilation systems and smoke extraction measures, tailored to the unique challenges posed by EV battery fires.

Organisational Fire Protection

- **Emergency Procedures and Training**: Guidelines for developing comprehensive emergency response plans, including staff training on handling EV-related fires.
- **Coordination with Fire Services**: Stipulations for coordination with local fire services for effective emergency response and management.

Preventive Fire Protection

- **Charging Point Regulations**: Specific rules and limitations on the installation of EV charging points, focusing on reducing fire risks associated with electrical faults or battery malfunctions.
- **Regular Inspections and Maintenance**: Mandates regular inspections and maintenance of EV charging infrastructure to ensure ongoing compliance with safety standards.

Additional Safety Measures

- **Public Awareness and Safety Information**: Encourages the dissemination of safety information to the public regarding the use of EV charging points and fire safety measures in parking areas.

2.5. Germany

[Model regulation on the construction and operation of garages and parking spaces (Model Garage and Parking Space Regulation M-GarVO1)]

- **Type**: Building code issued by the Conference of Ministers for Construction (a conference of specialist ministers of the German states)
- **Scope of Application**: National level, providing detailed guidelines for fire safety in parking structures.

Structural Fire Protection

- **Fire Compartments**: Emphasises the importance of fire-resistant walls, doors, and gates for compartmentalisation, with varying requirements based on the size and type of garage, and whether the garage is above or below ground. Materials must range from low flammability to non-combustible, ensuring structural stability in the event of a fire.

Technical Fire Protection

- **Fire Extinguishing Systems**: Depending on the size and type of the garage, various fire extinguishing systems are required, including dry water supply lines, semi-stationary spray water extinguishing systems, high-expansion foam extinguishing systems, and automatic fire extinguishing systems.
- **Smoke and Heat Extraction Systems**: Closed large garages must have mechanical smoke and heat extraction systems to manage fire-related smoke and heat.
- **Fire Detection Systems**: Garages larger than 2500 square meters must be equipped with fire alarm systems with both non-automatic and automatic fire detectors. If medium to large garages are connected to other parts of the building, a fire alarm system is required.
- **Safety Lighting and Signs**: Depending on the size of the closed garage, escape lighting and safety signs (for large, closed garages) or lighted signs for emergency exits (minimum 30 minutes without power) are required.

Organisational Fire Protection

- **Firefighters’ Water Supply and Access**: At feed-in points of the water supply, movement areas must be provided for fire brigade vehicles, with the feed-in points being not more than 15 meters away. These points must be determined in agreement with the fire protection department.

2.6. Greece

Law 4710/2020 "Promotion of Electrification and Other Provisions"

- **Type**: National law addressing the promotion of electrification and the safety of EV charging infrastructure.
- **Scope of Application**: National level, focusing on the installation, operation, and safety requirements for EV recharging points.

Structural Fire Protection

1. **Fire Compartmentalisation**: The guidelines emphasise the division of buildings into fire compartments with at least a 60-minute fire resistance rating, with stricter requirements in multi-use buildings. The installation of fire-protected escape routes with structural elements rated between 60 to 120 minutes, depending on the building's height, is mandated.

Technical Fire Protection

- **Fire Extinguishers and Systems**: The installation of carbon dioxide fire extinguishers with a minimum extinguishing capacity of 55B for every three EV charging points in enclosed parking areas is required.

- **Smoke and Heat Extraction**: The installation of smoke-heat exhaust systems according to EN-12101 is mandated in specific scenarios, such as basements larger than 200 m² or buildings with hazardous areas.

Preventive Fire Protection

- **Installation and Maintenance**: Electrical installations must comply with the Greek Standard ELOT 60364 or equivalent international standards. Installations in special safety areas must have the necessary certificates and approvals, with specific attention to safety shutters and protective barriers.

Joint Ministerial Decision No 42863/438/2019

- **Type**: National guidelines setting the terms, conditions, and technical specifications for installing EV charging devices.
- **Scope of Application**: National level, covering the installation of charging devices at vehicle service facilities, publicly accessible recharging points, and parking facilities in public and private buildings.

Structural Fire Protection

- **Fire Compartmentalisation**: Provisions apply for category B hazardous areas (electric vehicle charging areas), ensuring compliance with fire protection measures as outlined in related regulations.

Technical Fire Protection

- **Smoke and Heat Extraction**: The decision mandates the installation of smoke management systems in covered areas where charging devices are installed, with specific attention to hazardous zones.

- **Fire Extinguishers and Systems**: Appropriate extinguishing systems must be installed in line with the fire protection regulations for buildings, particularly in public and private parking areas.

Preventive Fire Protection

- **Location and Type of Recharging Points**: The decision specifies acceptable methods for charging (Mode 3 and Mode 4) and requires compliance with European and international standards for installation. Additionally, the placement of charging points must consider spatial planning, safety distances, and prohibited adjacencies.

2.7. Italy

Guidelines for the installation of electric vehicle charging infrastructure

- **Type**: Guidelines by the Italian firefighters
- **Scope of Application**: National level, including specific guidelines for the installation and management of EV recharging points.

Structural Fire Protection

- Italy's guidelines focus on fire risk assessment and mitigation in spaces where EV recharging points are installed. While there are general rules for places at risk of fire, the charging of electric vehicles is not considered to significantly change the risk level. The guidelines emphasise the importance of complying with fire prevention controls in places subject to such procedures.

Technical Fire Protection

- **Fire Extinguishers and Systems**: Mandates portable fire extinguishers at EV recharging points, suitable for electrical systems.
- **Emergency Controls**: Charging stations must have an emergency release control device for electrical isolation in emergencies.
- **Installation Safety**: Specific recommendations are made to avoid installation in areas with flammable gases or vapours.

Organisational Fire Protection

- The guidelines stipulate regular checks and documentation following any changes or modifications to the charging station, ensuring ongoing compliance with fire safety standards.

- Proper signage and information are required.

Preventive Fire Protection

- **Recharging Point Types**: Only mode 3 and mode 4 recharging points are allowed, with prohibitions on mode 1 and mode 2.
- **Inspection and Maintenance**: Regular visual inspections of recharging points are required, with at least weekly checks.
- **Installation Specifications**: Emphasises grounding of power cables with metal shielding.

2.8. Luxembourg

Fire prevention regulations - Covered parking for more than 20 vehicles

- **Type**: Technical Regulation developed and applied jointly by the fire brigade and the labour inspectorate.
- **Scope of Application**: National level, with specific focus on fire safety in covered parking lots accommodating more than 20 vehicles, including specifications for EV recharging points.

Structural Fire Protection

- **Fire Compartments and Materials**: Emphasis on the use of fire-resistant materials and compartmentalisation within parking structures. Specifically mentions the fire stability of the structure and the fire-resistance rating of floors, walls, and ceilings.
- **Accessibility**: Provisions for vehicle impact resistance in construction elements and adequate floor smoothness and impermeability. Minimum height restrictions for obstacles in parking lots to facilitate user movement and EV access.

Technical Fire Protection

- **Fire Extinguishing Systems**: Requirements for standardised portable fire extinguishers based on the number of cars per level. Enclosed parking lots of certain categories must have sprinkler systems.
- **Ventilation and Gas Control**: Mechanical ventilation systems are mandated to prevent stagnation of noxious or flammable gases, with specifications for natural ventilation and extraction circuit design.
- **Smoke Detectors and Fire Alarm Systems**: Obligatory installation of fire detection systems and fire/smoke doors linked to these systems. General alarm systems with push-button activation on all floors.

Organisational Fire Protection

- **Safety Recommendations**: Guidelines for slip-resistant vehicle and pedestrian walkways to enhance safety in the parking environment.

Preventive Fire Protection

- **EV Recharging Points**: Allows for normal and rapid recharging in charge modes 2, 3, and 4, using standards-compliant terminals and cables. Specific rules for electrical hazard management near charging stations and requirements for power supply cutoff by fire detection systems in case of alarms.

2.9. Norway

Regulation on low-voltage electrical installations

- **Type:** Regulation issued by the Norwegian Ministry of Justice and Public Security
- **Scope of Application:** National level, including specific guidelines for the installation and safety of electric vehicle (EV) recharging points in parking areas.

Structural Fire Protection

- **Fire Compartments:** Electrical installations such as appliance panels and distribution cabinets must be clearly arranged, easily accessible, and made of non-combustible, mechanically resistant materials. Wiring systems should avoid escape routes but, if necessary, must be protected to prevent fire spread or excessive temperatures.
- **Wiring systems:** Wiring systems in escape routes should be out of reach or protected against mechanical damage. It is recommended to use cables with insulation that does not emit harmful amounts of toxic gases during a fire.

Technical Fire Protection

- **Ambient Heating Systems:** Electric heating systems with forced air circulation must have independent thermostats and thermal release mechanisms to disconnect heating elements if high temperatures occur.

Preventive Fire Protection

- **Initial Control and Inspection of Recharging Points:** Electrical equipment must not endanger safety when installed and maintained correctly. Emergency disconnection equipment must be installed where quick disconnection is necessary to avoid danger.
- **Maintenance of Recharging Points:** Regular inspections are recommended, particularly in homes every ten years and more frequently

in industrial or agricultural settings. The installation must ensure accessibility for maintenance, repair, and testing without danger.

2.10. Poland

In Poland, different legislation/guidelines/building codes cover fire safety of EV recharging points in covered/above ground parking areas.

Regulation of the Minister of Energy on the Technical Requirements for Charging Stations and Charging Points

- **Scope**: National level, specific to EV charging points.
- **Fire Protection Aspects**: Charging points must be located outside potentially explosive zones. Requires a technical examination of charging devices, including a fire protection expert's opinion.

Act on Electromobility and Alternative Fuels

- **Scope**: National level covers installation of EV charging points in buildings.
- **Fire Safety Requirements**: Expert opinion on fire safety required for installation in multi-family residential buildings. Sets the standard for the number of EV charging points in new and renovated buildings.

Regulation of the Minister of Interior and Administration on Fire Protection Device Design

- **Scope**: National level, specific to fire safety in building design.
- **Technical Fire Protection**: Includes requirements for firefighting water supply systems with hydrants in garages. Specifies types of fire extinguishers and their placement based on garage size.

Act of July 7, 1994, Construction Law

- **Scope**: National level, relevant to construction and electrical installations.
- **Organisational Fire Protection**: Regulates the qualifications of designers, installers, and maintainers of electrical installations, including those for EV charging points.

Energy Law

- **Scope**: National level, relates to the operation of electrical devices.

- **Organisational Measures**: Details the qualifications and authorisations required for operators of EV charging points, ensuring compliance with safety and operational standards.

2.11. Romania

"Normative document regarding fire safety in underground car parks" code NP 127: 2009.

- **Type**: Technical regulation
- **Scope of Application**: National level, with specific provisions for electric vehicles (EVs) and recharging points in underground car parks.

Structural Fire Protection

- The Romanian guidelines focus on the structural aspects of fire safety in underground parking facilities, although specific mentions of fire compartments, access for EV removals, or other structural fire protection measures are not explicitly detailed in the document.

Technical Fire Protection

- **Ventilation Systems**: The guidelines mandate adequate ventilation systems at battery charging locations for electric cars to manage smoke and heat effectively.

Preventive Fire Protection

- **Limitation on Recharging Points**: The document restricts the number of battery charging equipment and terminals for electric cars to three for each car park. It also specifies that electric sockets for charging cars equipped with batteries and an internal charger, which do not produce hydrogen emissions, can be unlimited.
- **Connected Activities**: The guidelines authorise areas for connected activities, including battery charging points for electric cars, without requiring additional fire safety measures during the normal operation of underground car parks.

2.12. Slovakia

ATN_010 Safety aspects of electromobility - Garages in residential and non-residential buildings with parking spaces with infrastructure for electric cars

- **Type**: Guidelines on electromobility by the Ministry of the Interior of the Slovak Republic, the Presidium of the Fire and Rescue Corps
- **Scope of Application**: National, focusing on fire safety in relation to electric vehicle charging in garages.

Structural Fire Protection

- **Fire Compartments**: Utilises fire-resistant materials to segregate parking areas, with varying degrees of fire resistance required depending on the garage level.
- **Design and Layout**: Encourages a limited number of EV parking spaces within a single fire compartment to mitigate risk.

Technical Fire Protection

- **Fire Extinguishing Systems**: For parking lifts or similar devices used for EVs, the guidelines recommend the installation of a water-based fixed extinguishing system or an equivalent fire suppression method. The water supply intensity should be at least 14.7 $l \cdot min^{-1} \cdot m^{-2}$, as specified by the President of the Fire and Rescue Corps directive no. 39/2003. In collective and row garages, parking spaces and charging stations for EVs are advised to be equipped with automatic extinguishing systems with similar water supply requirements. Systems must be able to operate for a minimum of 120 minutes.
- **Smoke and Heat Extraction Systems**: Garages are recommended to be equipped with a system for the extraction of heat and combustion products, using forced ventilation to ensure a minimum of 10 air exchanges per hour. If natural cross-ventilation with at least 5% floor coverage is not available, this mechanical system becomes essential.
- **Fire Detection and Alarms**: In garages with more than 20 parking spaces for EVs and charging stations, the installation of an electric fire alarm system is recommended, especially for smaller garages with fewer than 50 vehicles.
- **Isolation Switches**: Charging stations should be equipped with an isolation switch to cut power in case of emergencies, preventing the risk of electric shock for firefighters and other emergency responders.

Organisational Fire Protection

- **Personnel Training**: Stresses the importance of training for staff on emergency procedures specific to EV fires, including the use of fire extinguishers and power isolation.
- **Emergency Preparedness**: Advises on the development of comprehensive emergency plans that incorporate the unique challenges posed by electric vehicles.

Preventive Fire Protection

- **Installation and Maintenance**: Dictates strict guidelines for the installation of charging points, emphasising regular maintenance and safety inspections.
- **Location Guidelines**: Provides specific recommendations for the placement of charging stations to facilitate emergency access and evacuation.

ATN® 010 - Safety Aspects of Electromobility: Garages in Residential and Non-Residential Buildings with Parking Spaces Equipped with Infrastructure for Electric Vehicles

- **Type**: ATN® 010 is a non-binding technical standard offering guidelines for the design, execution, and control of technical activities related to electric vehicle (EV) infrastructure in garages. While non-binding, it serves as a framework for voluntary compliance and can be adopted within contracts or competition tenders.
- **Scope**: National guidelines focusing on fire safety for garages that provide infrastructure for electric vehicle charging, applicable to both residential and non-residential buildings.

Structural Fire Protection

- **Fire Compartments**: The guidelines recommend separating fire compartments in parking areas using fire-resistant walls, doors, gates, or free spaces. Fire resistance of structural elements varies based on the garage level: 30 minutes for the top above-ground floors, 60 minutes for the first underground and above-ground floors, and 120 minutes for the second and lower underground floors. If fire compartments are equipped with a fixed fire-extinguishing device, the fire resistance requirements can be halved. These specifications aim to limit the spread of fire and protect both the building and its occupants.
- **Design and Layout**: The guidelines encourage limiting the number of EV parking spaces within a single fire compartment to mitigate risk. Proper distances between parked vehicles and compartment walls are essential to enhance fire safety.

Technical Fire Protection

- **Fire Extinguishing Systems**: A sprinkler system is recommended for underground parking levels with more than 50 spaces. The guidelines suggest that fire-extinguishing systems be coordinated with firefighting tactics to ensure protection against electric shock for responders.
- **Smoke and Heat Extraction Systems**: The use of Smoke and Heat Ventilation Devices (SHZ) is recommended in garage fire compartments. These systems must be designed following specific standards (STN EN 13501-4) to manage the anticipated amount of smoke and heat. In more complex layouts, a CFD (Computational Fluid Dynamics) simulation is advised to optimise ventilation system design.
- **Fire Detection and Alarms**: For garages with more than 25 parking spaces, of which at least 2 are equipped with charging infrastructure, fire detection and alarm systems are required. Automatic detectors should be installed in underground parking sections.
- **Isolation Switches**: Each charging station should include an emergency shutdown mechanism, allowing immediate disconnection in case of malfunction or hazard. The shutdown should be accessible to both users and emergency responders, with clear labelling.

Organisational Fire Protection

- **Personnel Training**: Technicians working on EV charging stations must follow strict safety protocols, with only certified personnel authorised to perform repairs or maintenance. Personal protective equipment (PPE) must be worn, and all actions should be documented for compliance.
- **Emergency Plans**: Fire evacuation plans should be posted in every garage. Additionally, in facilities with multiple fire devices, a fire response scenario must be developed, ensuring that each device operates effectively without disrupting others.

Preventive Fire Protection

- **Max Number of Recharging Points**: For new and renovated non-residential buildings, one charging point is required for every five parking spaces. This can present challenges for building electrical infrastructure, especially in larger garages.
- **Location of Recharging Points**: Charging stations should be located as close as possible to entrances or exits. Installing charging infrastructure on the second or lower underground floors is not recommended due to the difficulty of fire intervention.
- **Inspection and Maintenance**: Charging stations must undergo regular preventive inspections. Inspections should include checks on electrical wiring, functionality, and safety systems. Any corrective actions must be documented, with retesting performed after repairs.

2.13. Spain (Barcelona)

Technical guide "Electric vehicle recharging installations"

- **Type**: Guidelines developed by the firemen of Barcelona.
- **Scope of Application**: Local level, specifically tailored to Barcelona, with explicit guidelines for EV recharging points within the city.

Structural Fire Protection

- **Fire Compartments and Separation**: Mandates separation between EV Supply Equipment (EVSE) and parking spaces without EVSE, specifying distances or the use of E60 primary barriers for different power ranges of EVSE.
- **EV Removal Access**: Requires that EVSEs be located near facility entrances, enhancing accessibility for emergency services.
- **Evacuation Conditions**: Installation of EVSE must not compromise existing evacuation routes, ensuring safety during emergencies.

Technical Fire Protection

- **Fire Extinguishing Systems**: Outlines requirements for sprinklers and hose reels based on the power output of the connecting point, enhancing fire suppression capabilities.
- **Smoke Extraction and Detection**: Specifies the need for temperature control and smoke extraction systems for high-power EVSEs, alongside fire detection requirements to ensure early warning.
- **Hydrants and Safety Signage**: Installation of hydrants within proximity and information panels for firefighters, providing essential details for emergency response.
- **Power Supply Isolation**: A main switch to cut off all EVSEs, with automatic operation in areas equipped with sprinklers or fire detection, ensuring quick response to fires.

Organisational Fire Protection

- The guide does not explicitly detail organisational fire protection measures such as personnel training or firefighting strategies within the quoted sections.

Preventive Fire Protection

- **Recharging Point Regulations**: Delineates where EVSEs can be installed based on their power output, emphasising safety in residential areas and hospitals.
- **Inspection and Maintenance**: Highlights the importance of initial inspections and ongoing maintenance to ensure the safe operation of EVSEs, governed by specific regulations.

2.14. Switzerland

Guidelines on lithium-on batteries

- **Type**: Guidelines developed by Swiss association of insurers
- **Scope of Application**: National level, with clear specifications linked to electric vehicles and recharging points.

Structural Fire Protection

- The Swiss guidelines include stringent requirements for fire-resistant walls, doors, gates, and bulkheads to create effective fire compartments. The code specifies detailed fire stability ratings for structures and fire-resistance ratings for floors, walls, and escape routes. There are also clear regulations for the surface area of fire compartments in underground and above-ground car parks.

- In parking areas with one or more levels that are partially open, i.e. where the surrounding walls have at least 25% non-closable openings, the connected, non-compartmentalised surface area must not exceed 9,600 m2 per level.

- **Separating fire compartments with fire-resistant walls, doors and gates or fire dampers and bulkheads:**
  - Construction concept for parking in low rise buildings up to the height of 11m: REI30 for floor slabs forming fire compartment; EI30 for fire compartment walls and horizontal escape routes; REI30 for vertical escape routes.
  - Construction concept for covered parking in mid-rise buildings between 11m and 30m: REI60 for floor slabs forming fire compartment; EI30 for fire compartment walls and horizontal escape routes; REI60 for vertical escape routes.
  - Construction concept for covered parking in high buildings up to the height of 100m: REI90 for floor slabs forming fire compartment; EI60 for fire compartment walls and horizontal escape routes; REI90 for vertical escape routes.

- **Fire compartment:** The fire compartment surface area of underground car parks and closed above-ground car parks can reach 4,800 m2, provided that they have only one level or that each level constitutes a separate fire compartment. If the levels of multi-level car parks are in open connection, the fire compartment area must not exceed 2,400 m2. In car parks equipped with an extinguishing installation, the fire compartment surfaces can be doubled. When exits from a parking with a fire compartment surface area exceeding 1,200 m2 open into a vertical evacuation route, fire-resistant airlocks or vestibules must be constructed. The fire resistance of the airlocks must be equal to that of the supporting system, but at least EI 30. The doors of the airlocks leading to a vertical or horizontal escape route must have a fire resistance E30 and be fitted with automatic closing. Premises (with the exception of individual houses, small buildings and annex buildings) with a surface area of up to 600 m2 housing motor vehicles must form separate fire compartments.

Technical Fire Protection

- **Fire Extinguishing Systems:**
    - The code outlines the necessity of sprinkler installations in parking lots and garages based on specific criteria related to the fire compartment area and the building's structure. For parking in low rise buildings up to the height of 11m and in underground levels, walls and floors forming fire compartments must have the same fire resistance as the fire compartments corresponding to the assignment, but at least EI60. For parking in mid-rise buildings between 11m and 30m, REI30 for Floor slabs forming fire compartment; EI30 for fire compartment walls and horizontal escape routes; REI60 for vertical escape routes; R30 for supporting systems of the building. For parking in high buildings up to the height of 100m, R60 for supporting systems of the building; REI60 for Floor slabs forming fire compartment; EI30 for Fire compartment walls and horizontal escape routes; REI90 for vertical escape routes.
    - A safety power supply is required for emergency lighting of premises, escape routes and emergency signals, as well as for powering fire protection equipment such as sprinkler pumps, fire brigade elevators, firefighters and other important installations in the event of fire. In the event of a failure of the normal power supply, it must switch on in due time and for the prescribed operating time. Portable fire extinguishers are only recommended. Parking lots and garages for motor vehicles must be equipped with a sprinkler installation: underground garages with one or more levels whose fire compartment area per level is greater than 4,800 m2, as well as those with several levels, with open connections, whose fire compartment surface area is greater than 2,400 m2. Parking lots and garages for motor vehicles must be equipped with a sprinkler installation in closed above-ground garages with a fire compartment surface area greater than 4,800 m2 and those partially open (enclosing walls comprising at least 25 % of non-closable openings), on one or more levels, whose fire compartment surface area is greater than 9,600 m2 per level. Open connections are allowed. A sprinkler installation is required in mechanised or

automatic garages intended for compact parking of more than 50 vehicles. Sprinkler installations must protect annexes and covered spaces serving as warehouses or housing motor vehicles, trailers, containers, etc., when the fire compartmentation has insufficient fire resistance compared to neighbouring uses. The sprinkler systems must be located in separate fire compartments of the same fire resistance as the fire compartment corresponding to the assignment, but at least EI30. They must have safe and protected access (e.g. from the outside or from a vertical evacuation route) and be placed on the 1st floor, the ground floor or the 1st basement. Doors must have El30 fire resistance. Access routes to sprinkler systems must be signposted. An adequate access control system must be provided, which does not obstruct the intervention of firefighters. Any reaction from the sprinkler installation must immediately trigger an internal and external alarm. The external alarm must be transmitted directly to the official fire alarm centre.

- **Smoke and Heat Extraction Systems:** When the parking is underground or closed on all sides, then smoke and heat extraction installations are obliged for such parking areas larger than 600m2 and without extinguishing installation (surface of the fire compartment or people), or b) if larger than 3600m2 and with extinguishing installation (surface of fire compartment or people). In the case that parking is above ground and not covered by all sides, then smoke and heat extraction installations are obliged for such parking areas larger than 2400m2 if without extinguishing installation (surface of the fire compartment or people) and obliged if larger than 4800m2 and with extinguishing installation (surface of fire compartment or people). For above ground parking with 25% of its exterior walls open, then smoke and heat extraction installations are not obliged. Smoke and heat extraction installations should respect the following types for the above-mentioned parking: smoke extraction by firefighters' fans, natural smoke and heat extraction facilities, mechanical smoke and heat extraction installations. For parking lots, not only residential buildings, smoke extraction openings positioned directly to the outside must be provided in the upper part of the evacuation and rescue routes.
- **Safety Lighting and Signs:** Emergency signals in the parking must be equipped with lighting and have safety lighting for escape routes and escape routes inside the premises. In parkings, the direction of escape must be indicated by markings when it is not immediately recognisable or when the places are not familiar to the people who frequent them (for example in vertical and horizontal evacuation routes, or in the event of a change of management). Exits which are not immediately recognisable or which are only used in an emergency must be signposted. The signage must be easily recognisable and arranged so that at least one emergency signal is visible from any point in the premises. The signage of evacuation

routes and exits must be uniform within a building. Signs indicating escape routes and exits must be placed at the height of the door lintel, transversely to the direction of escape. Safety lamps powered by individual storage batteries must be connected to the overcurrent protection device in the same room. Emergency lighting must be checked according to the manufacturer's instructions, but at least twice a year for the prescribed operating time. An annual check is sufficient for safety lamps fitted with a working status indicator.

- **Isolation Switch for Power Supply:** Emergency lighting must not be able to be influenced by a main switch or by a switch for ordinary lighting in the premises. Centralised emergency lighting power systems must be divided into independent zones (groups). Malfunctions such as short circuits, interruptions or short circuits to earth must not have effects on other groups.

- **Safety Power:** A safety power supply is required for emergency lighting of premises, escape routes and emergency signals, as well as for powering fire protection equipment such as sprinkler pumps, fire brigade elevators, firefighters and other important installations in the event of fire. In the event of a failure of the normal power supply, it must switch on in due time and for the prescribed operating time. Safety power elements, such as overcurrent protection devices, switches, terminals and wiring, must be separated from the normal power supply to the floors by a fire resistance. Safety energy sources and the control panels relating to them must be installed permanently, in premises with a low fire risk. The fire resistance of these premises must correspond to that of the supporting system of the building, structure or fire compartment; however, it must achieve at least a fire resistance EI30. The doors must have a fire resistance EI30. Safety energy sources must be separated by a fire resistance EI60 from the distribution installations (connection devices and control) of the normal power supply. The installation of storage batteries is authorised in premises which do not present a fire danger. They must be protected by an EI30 resistance box. Rooms housing storage batteries requiring maintenance must be sufficiently ventilated in the ceiling area. Suitable energy sources, independent of the normal power supply, must be implemented for the safety power supply. The energy sources that can be used for security purposes are the following: storage batteries such as single, grouped or centralised batteries; generator sets consisting of an alternator whose engine operates independently of the normal power supply; an additional power line starting from the normal power supply, provided that it is independent of it and that the two lines cannot fail simultaneously. Powering escape route signs and emergency lighting via additional lines from the normal power supply is not permitted. Safety power supplies must be checked annually. Functional checks must be carried out in accordance with the manufacturer's data by qualified persons who have received the necessary instructions. The state of charge of the storage batteries must be checked annually and the operation of the generator sets every month.

Organisational Fire Protection

- The Swiss guidelines emphasise the need for a fire protection safety officer in larger buildings and complexes. These officers are responsible for ensuring fire safety and compliance with construction and equipment fire protection requirements.
- Electrical installations and charging stations: They must be installed by a professional Instructions for installation and use of charging stations must be followed. Terminals, cables, sockets, must be sufficiently large for the maximum reference power required by the vehicles and must be designed in compliance with the low-voltage installation standard SN 411000 (NIBT); SIA 2060 "Infrastructure for electric vehicles in buildings".
- Firefighter water supply and access: The firefighter elevator is required for high level building only or according to the access concept; the firefighter elevator is not an obligation for a standard parking lot.
- Intervention of firefighters: For buildings where there is an increased fire danger, it must be ensured that firefighters can be alerted and intervene quickly, for example by designing fire brigade intervention files, alarm and intervention concepts.

Preventive Fire Protection

- The code does not explicitly detail preventive measures specific to EV recharging points. However, it includes general provisions for the fire protection of parking lots and the restriction of mixed-use in areas designated for motor vehicles.
- Parking lots for motor vehicles with a surface area of more than 600 m2 cannot have any other use while parking must be fire protected.

2.15. The Netherlands

Dutch Building Decree / "Besluit Bouwwerken Leefomgeving"

- **Type**: National regulation addressing fire safety in parking structures housing BEVs.

- **Scope of Application**: National level, providing specific guidelines for fire safety in parking structures, particularly those accommodating EVs and recharging points.

Structural Fire Protection

- **Fire Compartments**: The Dutch Building Decree requires compartmentalisation with fire-resistant materials, emphasising the need for stability and fire-resistance ratings of floors and structural elements.

- **Access for Removals of EVs**: Guidelines suggest the preferable placement of EVs near entrances for easy removal, avoiding areas where ventilation air is supplied.

Technical Fire Protection

- **Fire Extinguishing Systems**: The decree recommends the installation of sprinklers or water mist systems, particularly in large or underground parking garages.

- **Smoke and Heat Extraction**: The Building Decree mandates that smoke extraction systems must comply with stringent ventilation requirements in case of fire.

- **Isolation Switch to Cut Power Supply**: A critical requirement of the Building Decree is the installation of a switch to cut off power to all recharging points, accompanied by a detailed map of EV parking spaces for use by the fire brigade.

Preventive Fire Protection

- **Type and Location of Recharging Points**: The decree mandates that all recharging points comply with Mode 3 or Mode 4 according to Dutch Standard NEN 1010, ensuring safety and consistency in EV charging infrastructure.

IFV Guideline Fire safety of indoor car parks accommodating electrically powered vehicles

- **Type**: Guidelines by IFV now the Netherlands Institute for Public Safety (NIPV)
- **Scope of Application**: National level, providing specific fire safety regulations for parking garages that accommodate electric vehicles (EVs) and recharging points.

Structural Fire Protection

- **Fire Compartments**: The guideline recommends compartmentalising parking garages into fire compartments or shielding between vehicles using physical fire separations such as walls, cladding, or fire screens. Additional recommendations include fire-resistant separation of the parking garage from adjacent spaces and the use of fire-resistant doors or shutters.

- **Access for removals of EVs**: EVs should not be placed where ventilation air is supplied, such as near the open facade of the parking garage. Placing EVs near entrances is preferable for easier removal. A plan should be developed to move EVs outside after a fire has been extinguished.

Technical fire protection

- **Fire Extinguishing Systems**: The installation of sprinkler or water mist systems is recommended, with these systems typically equipped with thermal detectors.
- **Smoke and Heat Extraction Systems**: The guideline suggests using smoke traps to prevent smoke from reaching escape routes, installing fire detection systems with smoke and/or heat detectors, and implementing gas detection systems for carbon monoxide. Exhaust ducts should be strategically positioned to manage smoke effectively.
- **Isolation Switch for Power Supply**: A facility must be available to switch off charging points, including a manual stop button, to ensure there is no electrical voltage during a fire. Various methods for switching off power are suggested, including vandalism-resistant emergency buttons and emergency switches/buttons on or near each charging station.

Organisational Fire Protection

- **Safety recommendations:** Residents and users should be given clear instructions on what to do in case of a fire. Fire detection systems should be connected to a fire alarm system that reports to a private alarm centre responsible for verifying reports and alerting the fire brigade if necessary. Sufficient cooling capacity should be available for firefighting.

Preventive fire protection

- **Location of recharging points:** Charging points should be located as close as possible to the entrances and exits of the garage, preferably at street level, and concentrated in specific locations within the parking garage. Charging points must be mode 3 or mode 4. Collision protection should be installed in front of the charging stations or positioned to prevent collisions.

NEN 6098 Standard "Smoke Control Systems for Powered Smoke Exhaust Ventilators in Car Parks"

- **Type**: National standard focusing on smoke control systems in parking structures.
- **Scope of Application**: National level, providing specific requirements for smoke control systems in car parks, including those with EVs and recharging points.

Structural Fire Protection

- **Fire Compartments**: The NEN 6098 standard emphasises the separation of fire compartments using fire-resistant walls, doors, and gates, with additional requirements for the stability of structures and fire-resistance ratings of floors.

Technical Fire Protection

- **Smoke and Heat Extraction**: The ventilation requirements according to this standard are specifically intended for use in the event of a fire. Additional ventilation requirements may be set based on the type of fuels other than petrol or diesel present in the parking area.

- **Other Technical Measures**: The standard also includes guidelines for smoke detectors, fire alarm systems, and fire extinguishing systems, which are crucial for maintaining safety in car parks with EVs.

Organisational Fire Protection

- **Safety Recommendations**: Recommendations include ensuring that personnel are trained and that the necessary organisational processes and risk assessments are in place to handle emergencies involving EVs.

Preventive Fire Protection

- **Location of Recharging Points**: The standard provides guidance on the optimal placement of recharging points to minimise fire risks and facilitate effective smoke control.

2.16. United Kingdom

RC59 by FPA: Recommendations for fire safety when charging electric vehicles.

- **Type:** Guidelines developed by the UK Fire Protection Association (FPA)
- **Scope of Application**: National level, with specifications directly linked to electric vehicles or recharging points.

Structural Fire Protection

- **Fire-Resistant Materials and Construction**: Although not explicitly detailed in the quoted sections, the overarching guidelines like RC59 typically recommend the use of fire-resistant materials in the construction of EV charging areas. This would involve specifications for the structural integrity of charging stations, ensuring they are built to withstand fire for a specified period, thereby preventing the spread of fire within a facility.
- **Design and Layout Considerations**: The guidelines would likely advocate for the strategic placement of EV charging points to minimise fire

risks, such as avoiding densely packed areas or locations that could impede emergency access or egress. The layout should facilitate quick isolation of any incidents to prevent fire spread.

- **Protective Barriers**: Recommendations may include the installation of physical barriers or protective measures to shield charging points from mechanical damage, which could lead to electrical faults and subsequent fire risks.

Technical Fire Protection

- **Sprinkler Systems**: Consideration for sprinkler protection in underground car parks, designed and maintained according to LPC Sprinkler Rules and BS EN 12845.
- **Automatic Fire Detection (AFD)**: Internal EV charging areas should be equipped with AFD installations, tested weekly and maintained in accordance with BS 5839-1.
- **Fire Fighting Measures**: Strategies include a fire risk assessment and emergency plan, with clear information available for emergency responders on the locations of EV charging points.

Organisational Fire Protection

- **Personnel Training**: Training for the safe use of charging equipment and actions in case of fire, including power isolation and evacuation procedures.
- **Emergency Plan**: Development of an emergency plan for fire incidents, emphasising manual isolation of charging points for safety.

Preventive Fire Protection

- **Location and Maintenance of Recharging Points**: Charging points should ideally be located outside, with clear differentiation for rapid charging points due to associated hazards. Maintenance to be performed by competent electricians.
- **Standardisation and Safety Measures**: Design considerations for disabled users, clear marking of vehicle parking bays, and comprehensive fire risk assessments to consider the risk from charging electric vehicles. Measures to prevent flammable material storage within charging areas and maintenance protocols for faulty chargers.

Risk Control Guide by RSA

- **Type**: Guidelines drafted by UK insurers
- **Scope of Application**: National, with specific attention to electric vehicles and recharging points.

Structural Fire Protection

- **Fire Compartments**: Advocates for a minimum of 120 minutes fire resistance for all parts of car parks, including structural members and separation between vehicle groups.
- **Design Considerations**: Recommendations include preventing the spread of fires through design features like floor slopes and drainage to control liquid flows.

Technical Fire Protection

- **Sprinkler Systems**: Stresses the importance of sprinkler protection, especially for below-grade car parks, adhering to high standards such as LPC and NFPA.
- **Fire Detection and Alarms**: Installation of smoke detection systems with settings to avoid false alarms from vehicle exhausts, linked to a constantly attended location.
- **Isolation Switches**: Emergency isolation switches for vehicle charging should be accessible for emergency shutdown.

Organisational Fire Protection

- **Personnel Training**: Training for the use of fire blankets and actions in the event of a fire is emphasised, including charging shutdown and evacuation.
- **Fire Fighting Measures**: Utilisation of vehicle fire blankets and appropriate fire extinguishers, with CO_2 or dry powder recommended for general fires.

Preventive Fire Protection

- **Charging Point Location**: Guidance on avoiding unsprinklered below-grade areas for chargers, with a preference for roof areas or well-ventilated locations.
- **Maintenance and Inspection**: Establishes protocols for regular inspections and maintenance of charging equipment by competent personnel.

T0194 – Covered Car Parks - Fire Safety Guidance for Electric Vehicles by ARUP

- **Type**: Guidelines drafted by Arup, a collective of engineering and sustainability consultants, designers, architects and experts working globally.
- **Scope of Application**: This guidance applies nationally, focusing on the fire safety measures required within covered car parks that accommodate

EVs, addressing both new designs and modifications to existing structures.

Structural Fire Protection

- **Material Requirements**: The guidance specifies the use of fire-resistant materials in the construction of EV parking areas to prevent the ignition and spread of fire. It suggests materials with a minimum fire resistance rating, aiming to contain fires within localised areas and prevent structural collapse.
- **Design Considerations**: Emphasises the importance of car park layouts that facilitate fire containment and egress during emergencies. Recommendations include adequate spacing between parked EVs, the use of physical barriers to protect EV charging points and ensuring that EV charging areas are easily accessible for firefighting efforts.

Technical Fire Protection

- **Fire Detection Systems**: Advocates for the installation of comprehensive fire detection systems that include smoke alarms and thermal imaging to quickly identify fires within EV charging areas.
- **Fire Suppression Systems**: Suggests the integration of automatic fire suppression systems, such as sprinklers, specifically designed to address the unique challenges posed by EV fires. These systems should be capable of activating in the early stages of a fire, providing critical response time for evacuation and firefighting efforts.
- **Emergency Power Cut-off**: Stresses the need for easily accessible emergency power cut-off mechanisms for EV charging stations to quickly isolate electrical supply in the event of a fire, minimising the risk of electrical fires spreading.

Organisational Fire Protection

- **Emergency Response Planning**: Requires the development of specific emergency response plans for EV fires, including evacuation protocols and the role of staff in emergency management. Training for staff on the use of fire safety equipment and procedures for safely handling EV fires is also emphasised.
- **Information Sharing with Fire Services**: Encourages the sharing of detailed plans and information about the location and operation of EV charging stations with local fire services to aid in emergency planning and response.

Preventive Fire Protection

- **Regular Inspections and Maintenance**: Mandates regular inspections and maintenance of EV charging stations to ensure they remain in good working order and compliant with fire safety standards. This includes the inspection of electrical connections and the physical condition of charging points.

- **Risk Assessments**: Recommends conducting detailed risk assessments that consider the specific hazards associated with EV charging in covered car parks. These assessments should inform the design, operation, and emergency planning for car parks to ensure a comprehensive approach to fire safety.

3. Key challenges related to fire safety of BEVs in covered parking lots

In the rapidly evolving world of BEVs, fire safety in covered parking facilities has become a critical concern. While fires pose risks in any context, the unique characteristics of BEVs require a nuanced understanding of the potential hazards. This chapter highlights the key challenges associated with fire safety in covered parking lots for BEVs. By exploring these issues, it aims to provide valuable insights for public authorities and private stakeholders to consider when evaluating changes to guidelines, legislation, or safety practices. The discussion underscores the importance of a comprehensive approach to fire safety in light of the growing adoption of BEVs, fostering a safer environment for both users and emergency responders.

3.1. Fire safety challenges linked to the lithium-ion BEVs

3.1.1. Types of potential dangerous phenomena

The current fire safety requirements for BEVs are inadequate to significantly reduce the likelihood of hazardous events.[27] Furthermore, lithium-ion batteries in BEVs pose several risks, including thermal runaway, fires, jet fires, and vapor-cloud explosion (VCE), along with the potential for reignition or delayed ignition. The following sections in this chapter will outline and describe each of these risks. It is worth noting, however, that while these risks associated with battery packs exist, data from the Nederlands Instituut Publieke Veiligheid (NIPV) shows that nearly half of electric vehicle fires do not involve the battery packs.[28]

Thermal runaway is one of the primary risks associated with lithium-ion batteries. It occurs when a lithium-ion cell enters an uncontrollable, self-heating state through an exothermic reaction. This phenomenon begins within the battery cells, leading to their decomposition and potentially resulting in thermal propagation within the battery pack. This process can continue with the release of gas and smoke and may ultimately escalate to a fire.

A battery pack consists of numerous cells, each separated by a critical component called the separator, which isolates the anode (-) from the cathode (+). Thermal runaway can be triggered by a defect in a cell's separator, often caused by physical, thermal, or electrical abuse. Once initiated, thermal runaway involves a rapid overheating event where elevated temperatures or excessive

[27] (Troitzsch, 2022)
[28] (*NIPV Annual Report 2022*, 2023)

voltage initiate chemical reactions within the battery cell. If the battery's cooling system is overwhelmed, ignition can occur. This ignition can, in turn, heat adjacent cells, leading to thermal propagation.

The more cells affected by thermal runaway within a battery pack, the greater the likelihood of a fire spreading through successive cells. This chain reaction can ultimately result in the failure of the entire battery pack.

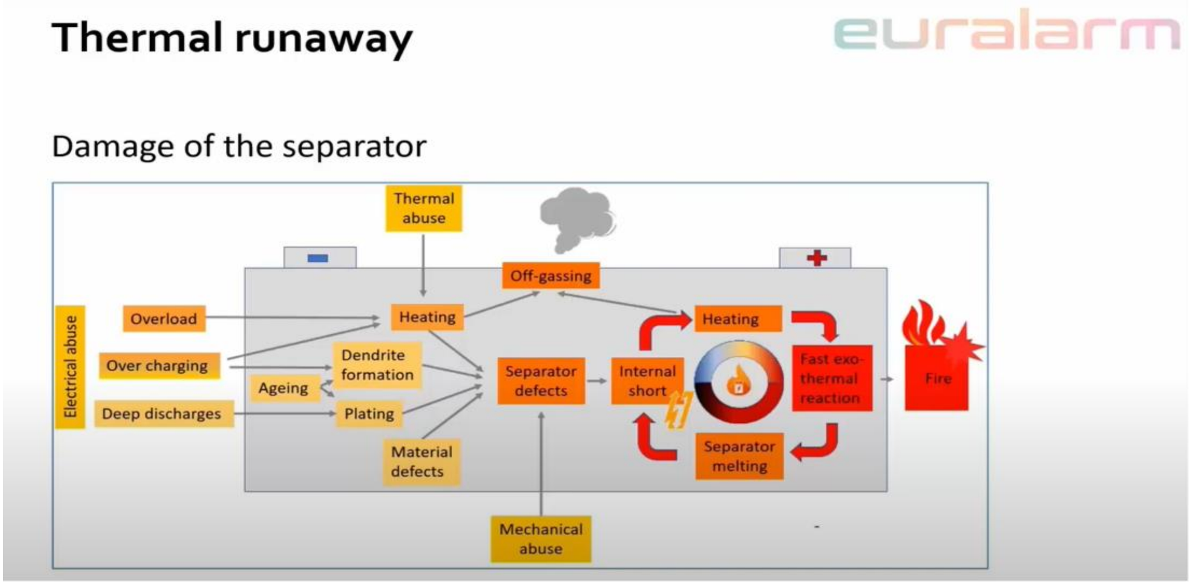

Diagram of thermal runaway, Euralarm

Thermal runaway can sometimes begin at relatively low temperatures (approximately 90–120°C), often as a result of overcharging. The temperature rises rapidly as the failing battery releases flammable gases, which can ignite in the presence of an ignition source or if the surrounding environment provides the necessary conditions for combustion—namely sufficient oxygen generation, a fuel source, and heat. A fully charged battery experiencing thermal runaway generates a significant amount of heat and gas that may ignite when vented from the battery cell. Short circuits can further contribute to ignition. However, if the battery is discharged or has a low charge level, there may be insufficient energy in the cell to heat the released gas to its ignition point, allowing the gas to vent without igniting.[29]

Beyond mechanical damage or external thermal abuse, thermal runaway usually occurs when the Battery Management System (BMS) fails to implement countermeasures to address battery issues such as overheating. This can lead to a range of reactions, including fires and explosions of released gases, with potentially severe consequences in confined spaces. Several scenarios are possible:

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[29] (*Guidelines for Fire and Rescue Services: Risk Assessment and Handling of Fire in Lithium-Ion Batteries*, 2021)

- **Free-burning fire:** Flammable gases ignite when exposed to an ignition source, such as hot metallic particles inside the battery pack.
- **Jet fire:** Gases vent with momentum, producing directional flames, often designed to escape from the side of a vehicle to reduce overpressure.
- **Flash fire:** Vented gases mix with air within their flammability range, resulting in a deflagration (a rapid combustion event below the speed of sound) that may quickly consume all available vapor without igniting other materials.
- **Vapor cloud explosion (VCE):** A cloud of flammable gases forms and explodes if ignited under conditions of sufficient confinement.

Additionally, various volatile components, such as benzene, toluene, and ethanol, can be released during the thermal decomposition of materials like polystyrene, ABS, and other resins, as seen in ICEV fires. Fire extinguishing water may also become contaminated with harmful substances, including metals and halogens. One significant risk associated with BEV fires is the potential for reignition after the initial extinguishment. Reignition is dependent from residual stranded energy and the internal pack temperature following the primary extinguishment. This occurs when other cells within the battery pack, damaged during the initial event, later enter thermal runaway. Such later reignitions have been observed during real-world testing[30] and pose challenges for firefighters in managing BEV fires effectively.[31] To address these challenges, some vehicle manufacturers are developing new housing technologies that allow firefighters to directly access the battery packs with fire suppressants, enhancing their ability to manage and extinguish BEV fires safely.

3.1.2. Causes of battery fires

Batteries are more likely to catch fire when damaged. Four main categories of factors can lead to fires as explained in the table below:

Cause of battery fire	Explanation
Thermal abuse	Thermal abuse in lithium-ion batteries occurs when external factors, like a nearby fire, elevate temperatures. The first step is the decomposition of solid electrolyte interphase (SEI) film and electrolyte occur at 80°C and 100°C respectively, among which the chemical reactions between the negative electrode and the electrolyte could occur as well.

[30] Li-ion battery full scale thermal runaway test: environmental and personnel exposure influence in case of rescue operations.
[31] (Hynynen et al., 2023)

Electrical abuse	Electrical abuse happens when the current surpasses the maximum energy storage limit, converting power into heat. If this heat is not dissipated fast, the battery temperature rises, causing overheating and potentially leading to thermal runaway. An over-current event like in short circuits generates excessive heat, creating an electrically abusive situation that can lead to material decomposition.
Mechanical abuse	Mechanical abuse happens when a battery undergoes physical damage, like collisions or hitting obstacles. This can lead to various issues, with the most common being a short-circuit. A short-circuit causes current to flow through the conducting terminal, creating heat in the cell. If this heat is not dissipated quickly, the battery cell can enter thermal runaway.
Flood damages	Battery electric vehicles adhere to rigorous standards (UNECE Regulation n°100 - Revision 3, with amendments effective from 14 September 2017) to ensure minimum protection against solid particles and water. However, damaged battery packs, such as those from collisions, pose a risk, especially of saltwater entering and potentially causing short-circuits between cells.

The speed at which thermal runaway propagates is intrinsically tied to the efficacy of the chosen safety strategy and the materials used in the battery system. Robust safety strategies at cell, module or pack level, including thermal insulation, flame-retarding materials, and advanced cooling systems, significantly slow down the propagation of thermal events. Additionally, State of Charge (SoC) will play a big part on the thermal propagation.

3.2. Challenges and risks related to the recharging infrastructure

Recharging infrastructure for BEVs involves several risks in the following scenarios:

- Installations are not performed in compliance with applicable safety regulations.
- The installer lacks proper qualifications for BEV charging installations.
- Electrical equipment used is unsuitable or unsafe.
- Maintenance or inspections are not conducted properly.
- Incidents of vandalism.

To better understand the challenges and risks associated with BEV recharging infrastructure, it is essential to recognise that there are four distinct recharging modes, each with its own fire risks. The table below provides a description of these modes.

Recharging mode	Description	Protection level
Mode 1	• Connection of an EV to a standard socket-outlet of an alternating current (AC) supply network by utilising a cable and plug. Both of which are not fitted with any supplementary pilot or auxiliary contacts. *Note: Not allowed in the United States of America, Israel, and the UK; prohibited for public recharging in Italy; restricted in Switzerland, Denmark, Norway, and Germany.*	• Non-dedicated power sockets • Simple cable • Risk of overheating • No other residual current device than that installed at the origin of the installation, if any.
Mode 2	Connection of a BEV to a standard socket-outlet or a reinforced socket-outlet of an AC supply network utilising an AC BEV supply equipment with a cable and plug, with a control pilot function and system for personal protection against electric shock placed between the standard plug and the EV. Typical portable / "emergency" charger. *Note: Prohibited for public recharging in Italy; restricted in the United States of America, Canada, Switzerland, Denmark, France, and Norway.*	• It should be set up with a new dedicated circuit and a dedicated socket-outlets. • Dedicated cable (IC-CPD) should include control and safety functions. • Setting of the IC-CPD current depends on the national regulation. • IC-CPD includes residual current device, control of earthing continuity.
Mode 3	Connection of a BEV to an AC BEV supply equipment permanently connected to an AC supply network, with a control pilot function that extends from the AC BEV supply equipment to the BEV. *Note: It includes bidirectional communication. Tethered (cable permanently attached) and untethered (dedicated socket outlet only) configurations are available. This is a typical public AC charger installation mode.*	• Dedicated recharging infrastructure incorporating charge and battery temperature monitoring; • Possible communication with parking lot supervision system and fire alarm system; • Dedicated cable.
Mode 4	Connection of a BEV to an AC or direct current (DC) supply network utilising a DC BEV supply equipment, with a control pilot function that extends from the DC BEV supply equipment to the BEV. *Note: This is a typical installation for "fast charging", "ultrafast charging", "rapid charging" and similar terms.*	• Dedicated power socket incorporating charge monitoring; • Dedicated cable; • Residual current device included.

In addition to the elements listed in the table above, fire hazards related to BEV recharging points can stem from short circuits, overloads, and over-currents. The use of polymer flame-propagating materials in components like enclosures, plugs, and sockets further contributes to this risk. However, these hazards can be significantly mitigated by using non-flame-propagating products and installing EV charging points in compliance with the relevant EN/HD and/or IEC standards.[32]

[32] (*De Verschillende Technieken van Laden: Mode 1, 2, 3 En 4* | *MobilityPlus (NL)*, 2018)

Furthermore, charging Mode 2 may be utilised by an existing electrical installation, where the vehicle is connected through a household socket via a charging cable equipped with an In-Cable Control and Protection Device (IC-CPD). During charging, a steady current flows over an extended period. The IC-CPD limits the current, which may reach up to 20 A depending on the model. Modern electrical installations typically design general-purpose socket circuits with a maximum current of 16 A, ensuring that protections and conductors can handle this safely. In installations adhering to wiring regulations, if the circuit exceeds its design current, the overload protection device will activate to safeguard the circuit. However, in non-compliant installations, protective devices may fail to respond in time, and cables might suffer damage from prolonged overloads. Supplying high currents over long durations in such installations poses a serious fire risk. Although newer IC-CPD models (compliant with future EN IEC 62752 standards) include thermal monitoring to prevent overheating and manage current flow, these safety features can be bypassed through the use of extension cords, power boards, additional measurement devices, or travel adapters.

Another risk associated with recharging points is the lack of regular inspection requirements for electrical installations, including recharging points, either at the time of commissioning or as part of regular inspections.[33] While some EU Member States have specific requirements in this aspect, this is not a uniform approach across the Union. The absence of inspections can lead to substandard installations, particularly if recharging points are installed by unqualified personnel, thereby increasing the risk of fire. With the growing demand for recharging stations and a shortage of skilled workers, the pressure to deploy installations rapidly is intensifying. This urgency can strain the workforce and compromise the quality of installations. Proper training for installers is essential to ensure compliance with safety and electrical standards. Recharging points should only be installed by professionals with adequate qualifications, not by individuals who have received minimal training through short courses or lack official certifications. Reliance on underqualified workers increases the likelihood of improper installation, posing risks to both the workers and the recharging infrastructure.[34]

While the risk of fires during the installation of recharging stations is relatively low, electrical safety risks for workers remain a concern. These risks, closely linked to fire hazards, can arise from poor installation practices. In Europe, nearly 47% of accidental residential fires are caused by electrical issues.[35] Improperly installed recharging stations, particularly those connected to building or grid electrical systems by unqualified workers, heighten fire risks. Even after the initial

[33] (Hynynen et al., 2023)
[34] (McGlone, 2022)
[35] (*White Paper: Accidental Electrical Domestic Fires*, 2021)

installation, electrical safety concerns can emerge over time. These issues might result from equipment wear and tear or user interference with the system. Such risks are more pronounced when recharging points and their electrical installations are not regularly inspected and maintained.[36] It is crucial that operators of recharging stations conduct maintenance and inspections using fully qualified personnel. Regular checks help mitigate risks associated with aging equipment and ensure the long-term safety of the installation.

3.3. Challenges and risks related to human safety and firefighters intervening on the scene

As with any type of vehicle fire in enclosed spaces, especially in residential buildings, BEV fires can pose significant threats to human life, including the safety of emergency responders on the scene. Fires can quickly spread between vehicles—both ICEVs and BEVs—potentially trapping individuals in parking areas with smoke or flames, leading to casualties. Vehicle fires, regardless of whether they involve ICEVs or BEVs, release toxic gases and substances.

Even though BEV fires do not inherently carry an aggregated risk of toxic gas emissions, fires, including those involving BEVs, produce various gases that can irritate airways and cause corrosion, such as hydrogen chloride, sulphur dioxide, and hydrogen fluoride (HF). HF is not exclusive to BEV fires; it is also released in fires involving fluoride-containing products commonly found in ICEV fires and household polymers. In fact, HF is present in almost all house fires, posing a longstanding risk to fire services. Exposure to HF and hydrofluoric acid can occur through inhalation or skin absorption. Inhaling fire smoke, including HF gas, can cause severe lung damage and impair oxygen absorption.

Similarly, combustion gases from any vehicle fire are toxic and can lead to incapacitation. Carbon monoxide (CO) and hydrogen cyanide (HCN) are common causes of death in fire incidents involving smoke inhalation.[37] CO, in particular, is the dominant toxicant in such scenarios as it forms whenever organic materials burn. Halogen-containing materials, such as brominated flame retardants, are more challenging to ignite and burn more slowly than non-halogenated equivalents. This slower burning rate can result in a reduced release of gaseous combustion products, especially if delayed ignition or rapid self-extinguishment occurs.[38]

When responding to BEV fires, emergency personnel, especially firefighters, must employ distinct strategies compared to ICEV fires, particularly if the BEV's

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[36] (*White Paper: Accidental Electrical Domestic Fires*, 2021)
[37] (Eckstein & Maniscalco, 2006)
[38] (Sergei Levchik et al., 2011, p. 240)

battery pack enters thermal runaway. Despite differences, there are significant design similarities between BEVs and ICEVs, which pose similar risks for firefighters in enclosed parking areas due to the increased flammability and toxic vapours released by modern vehicles with more combustible materials. In BEV fires involving the battery pack, additional gases are released from the burning electrolyte and lithium-ion salts. Studies, such as those by Lam et al., suggest that while ICEV fires typically have a single peak heat release rate (HRR) followed by a steady decline, BEV fires often exhibit two peaks: one when combustible materials ignite and another when the battery becomes involved. Research by Kang et al. further indicates that BEV fires may have slightly lower peak heat release rates (pHRR) and total heat release than their ICEV counterparts.[39] For BEV fires, the primary heat contribution comes from the combustion of conventional body materials rather than the battery pack itself. However, thermal runaway in the battery can produce a jet fire, accelerating the spread to nearby combustible components and the rest of the vehicle.

Firefighters must carefully evaluate each fire situation to choose the most appropriate methods, tactics, and technologies, as strategies for addressing BEV fires continue to evolve. To ensure safety during vehicle fire interventions, firefighters may use towing equipment to move vehicles into open-air environments, but this is only feasible if the vehicle is not in thermal runaway. Such operations depend on factors like visibility, temperature conditions, and the management of re-ignition risks. Additionally, the combination of lithium and water can produce combustible hydrogen, further complicating firefighting efforts. Maintaining a safe distance and wearing protective equipment, such as 1,000-volt gloves, is critical near batteries and high-voltage circuits. Contact with live cables carrying high DC voltages in EVs can result in fatal electrocution, with injury severity depending on factors like current intensity, voltage, the conductive path, and exposure duration. Even when a fire appears to be under control, risks such as liquid splashes, spontaneous reignition, and explosions remain. Reignition, often signalled by white smoke without a significant temperature increase, can occur suddenly, while explosions can create dangerous missile effects. Furthermore, upon arrival, firefighters may lack crucial information about the vehicles involved or the presence of thermal runaway, making it harder to formulate an effective attack strategy.

[39] (Kang et al., 2023)

3.4. Challenges and risks for parking operators and building owners

As BEVs become increasingly common on European roads, parking lot operators and building owners must prioritise fire safety by providing essential services such as parking facilities and recharging infrastructure for BEVs. A key concern for these stakeholders is ensuring the safe parking of both BEVs and ICEVs, particularly in enclosed spaces beneath or adjacent to buildings. This is vital to ensuring public safety. Accommodating BEVs presents unique challenges for parking operators and building owners, especially given the diversity in building construction and design. Establishing consistent fire safety standards for both new and existing structures is difficult, as some preventive measures are not feasible in existing buildings. The increasing size of vehicles of both ICEVs and BEVs further exacerbates the issue, reducing available space and increasing the risk of fire spread and structural damage. Moreover, the use of proper recharging infrastructure is critical. In the absence of designated recharging stations, BEV drivers may resort to non-compliant equipment, which can significantly elevate fire risks.[40] Addressing these challenges, along with implementing necessary fire prevention measures, places financial burden on operators and building owners as they adapt to the evolving automotive landscape.

3.5. Challenges and risks for insurers

The mission of the insurance industry is to provide consumers and businesses with protection against adverse events, such as a fire in a parking garage. Consequently, improving the fire safety of BEVs in covered parking spaces is highly relevant to the insurers. Furthermore, since the risks and losses from a battery fire are not confined to the BEVs itself but can escalate, causing significant property damage, loss of life, and serious injuries, insurers across Europe are assessing how the growing electrification of mobility may impact their ability to offer affordable risk protection. Although current data and research on this evolving risk landscape remain limited, existing studies offer valuable insights and direction for further action, particularly regarding BEVs in covered garages.

One such study, conducted by VdS Schadenverhütung and the German Insurance Association examines the fire risks associated with BEVs parked in enclosed medium- and large-sized garages. The findings emphasise that fire risks are inherently higher in enclosed parking spaces, primarily due to the release of extreme heat and smoke gases—regardless of whether the vehicle is electric or powered by a traditional combustion engine. Additionally, there are risks tied to recharging infrastructure for BEVs, the recharging process, and

[40] (Hynynen et al., 2023)

potentially defective or damaged vehicle battery systems. According to a study by reinsurer Swiss Re[41], fire safety risks may arise when multiple vehicles are recharging simultaneously or queuing to use recharging facilities in confined spaces, such as office parking garages, residential building lots, or commercial/retail premises. Issues with recharging infrastructure can lead to third-party property damage and liability claims, underscoring the need for tailored risk prevention and management strategies.[42]

3.6. Risks for the environment

This final section addresses the environmental risks associated with fires involving BEVs. BEVs possess unique characteristics due to their batteries and associated components. However, it is important to emphasise that, aside from the battery, the environmental impact of BEV fires is largely comparable to that of ICEV fires. Both types of fires emit toxic fumes, contaminate firefighting water, pollute rainwater and soil, and endanger surrounding plant and animal life. The table below outlines the primary risks associated with BEV fires and specifies whether these risks are unique to them or not.

Environmental Impact Categories	**Description**	**Inherent to BEVs (Yes / No)**
Air pollution / Toxic emissions	• Metal Oxides: Lithium-ion batteries contain various metals, such as cobalt, nickel, and manganese. When they burn, these substances can be oxidised and released into the air as fine particles. These metal oxides are harmful when inhaled and can cause respiratory problems. • Carbon Dioxide (CO2): Although less toxic than other emissions, CO2 is a greenhouse gas that contributes to global warming. Its release in large quantities can have a negative environmental impact. • Volatile Organic Compounds (VOCs): These compounds can be emitted during the combustion of polymer materials and other organic components of the vehicle. VOCs can include substances such as benzene, which is known to be carcinogenic. • Dioxins and Furans: These are persistent organic pollutants that can be formed during the combustion of materials containing chlorine. These substances are extremely toxic and can have harmful	No. • These types of emissions are inherent to all types of vehicles burning whether ICE or BEV. However, HF has been detected in higher quantities in BEV fires than in ICEV fires. During the fire extinguishing, water spray cooling used in conjunction with halogenated extinguishants reduces the peak HF concentration and the decay time.

[41] (*Risks along the Value Chain – Part I*, 2023)
[42] (*Risks along the Value Chain – Part I*, 2023)

	effects on human health and the environment. ● <u>Fine Particles (PM2.5 and PM10):</u> HF detected in higher quantities in BEV fires among the presence of other fine particles can be emitted by the combustion of vehicle materials. They are particularly dangerous because they can penetrate the lungs and even enter the bloodstream. ● <u>Other Toxic Gases:</u> Gases such as CO, nitrogen oxides (NOx), and other toxic compounds can also be emitted during the fire of a BEV. Concerning the hydrogen gas released from fire, liquid fuels (such as petrol and diesel) are more likely to initiate or contribute to the fire at an early stage, for example, liquid pool fires, than alternative fuels such as fires of BEVs. Here, an offensive tactic could be effective, but the personnel that fight the fire needs to be prepared for the fuel-dependent hazards that may occur.	
Extinguishing waters	● Lithium-ion battery fires require specific extinguishing techniques. The use of water or chemicals to control these fires can also have an environmental impact. The water used will be polluted and due to their quantity will not be collected and treated. They could be evacuated through the stormwater networks through the separators or collected, transported and treated in authorised disposal facilities.	No ● While the water used to extinguish lithium-ion battery fires is contaminated by specific elements present in the batteries, any vehicle fire will contaminate the extinguishing water. In addition, some methods of extinguishing BEV fires include water tanks that allow specialised services to treat this water afterwards.
Sludge treatment sector	● These sectors will have to adapt to be able to treat the pollutants inherent in this type of incident.	Yes ● While the water used to extinguish lithium-ion battery fires is contaminated by specific elements present in the batteries, and when, in the majority of cases, fire water is collected by public drainage systems, it ends up in wastewater treatment plants.
Rainwater wastewater treatment sector	● Depending on the cities, rainwater flows directly into the natural environment, which will have the effect of creating major pollution of aquatic environments. When the waters are treated in a treatment plant (activated sludge or aerated lagoon treatment), the microbiological processes are not designed to treat these pollutants, which could even destroy the bacteria and microorganisms of the treatment plants.	No

Water and Soil Pollution	• The chemicals and heavy metals present in the batteries of electric vehicles can seep into the soil and groundwater in the event of a fire (due to extinguishing waters), thus causing potentially dangerous pollution.	No
Impact on Wildlife and Flora	• If a fire occurs in or near natural spaces, it can have a direct impact on local wildlife and flora, disrupting ecosystems and destroying habitats.	No
Post-Fire Waste Management	• After a BEV fire, debris and battery components must be treated as hazardous waste. Their disposal and recycling require specific procedures to avoid further contamination.	Yes • Authorised treatment facilities need to consider the recycling of specific battery components.

4. Existing practices to facilitate the deployment of BEVs in covered parking lots while maintaining high fire safety standards

Maintaining fire safety in covered parking lots is not simply a matter of selecting specific measures and tools to install. Rather, it requires a combination of strategies to ensure an adequate level of safety. This section explores best practices for both preventing fires and managing them if they occur. It is important to emphasise that the measures required will differ between buildings designed for residential or public use and those intended solely for parking vehicles.

This chapter is structured around five key pillars, which represent the fundamental aspects to consider when developing a fire safety strategy for covered parking lots in relation with the safety of BEVs:

- Prevention of fires
- Detection of fires
- Evacuation
- Propagation control
- Fire extinguishing

In addition to these pillars, it is crucial for any building accommodating BEVs to conduct its own risk assessment. Such an assessment should account for the specific types of vehicles, the recharging infrastructure in place, and the materials used within the parking area. Particular attention must be given to existing parking facilities, which comprise the majority of current infrastructure compared to newly constructed ones. Local and regional authorities are therefore strongly encouraged to implement comprehensive fire risk assessments for existing covered parking facilities as these assessments play a vital role in ensuring user safety and minimising fire risks. By providing a detailed and objective analysis of current infrastructure, these evaluations offer actionable recommendations for improving safety. They also support the development of phased action plans tailored to the constraints of individual operators, enabling a systematic and effective approach to enhancing fire safety standards.

4.1. Prevention of fires

Preventing fires is a critical measure to reduce the risk of ignition. When addressing fire prevention, three key aspects should be considered: access conditions to covered parking lots, the design of recharging infrastructure, and the materials used in parking lot construction.

4.1.1. Access of BEVs in covered parking lots

As noted earlier, based on the existing research findings, BEV fires do not occur more frequently than those involving ICEVs. Therefore, restricting BEV access to covered parking facilities is neither practical nor beneficial. Such restrictions could hinder the adoption of BEVs and contradicts with the environmental goals set by the EU. For these reasons, it is advisable that BEVs are allowed to park in covered parking areas. However, it is important to recognise that, like other vehicles, damaged BEVs pose a fire risk. To minimise potential hazards, it is advisable to prohibit damaged vehicles from parking in covered parking lots.

In the event of flooding, especially when saltwater is involved, BEVs should be evacuated from covered parking areas and stored outdoors for a few days. Owners and emergency responders should remain vigilant for signs of battery fires, such as vapour clouds resembling smoke (either dark or light) and unusual sounds like hissing or hooting.

4.1.1.1. Existing practice

The fire safety guideline in Luxembourg permits only BEVs with a European Certificate of Conformity to be allowed to be recharged in covered parking lots.[43] The European certificate of conformity confirms that the vehicle is authorised and can therefore obtain a registration mark to legally circulate on public roads. Building on this good practice, EU Member States can ensure that the current condition of BEVs is well-maintained, allowing only vehicles that comply with safety regulations to be present in covered parking lots. This approach helps prevent damaged vehicles from occupying these spaces, thereby mitigating potential risks.[44]

4.1.2. Deployment of recharging infrastructure in covered parking lots

In order to avoid any fire linked with the electrical risk coming from recharging points, it is essential to address this risk and prevent fires related to electric malfunction. In 2021, a survey analysing electrical risks of newly installed charging point in residential buildings in France was conducted by CONSUEL, which ensures compliance with the safety requirements imposed by the regulations in force relating to electrical installations, by delivering the relevant

[43] (L'Inspection du travail et des mines et le Service Incendie et Ambulance de la Ville de Luxembourg, 2017)

[44] (L'Inspection du travail et des mines et le Service Incendie et Ambulance de la Ville de Luxembourg)

Certificates of Conformity. The survey was performed from the analysis of 616 new installations, representing 28% of the installed recharging points that year. From the survey, the main defaults observed in residential buildings are the following:

- 14% Bad execution
- 9% Overcurrent

Less frequent (≤ 5%) issues have been observed on:

- Protective earth conductor (PE)
- Unsuitable charging point
- Earthing
- Inadequate sizing (cable section)
- Residual Current Device
- Cut off
- Protection against short circuit

Socket outlets according to national standards also cover all applicable safety requirements, including requirements for protection against fire risk. Furthermore, ensuring the safe deployment of recharging points necessitates a three-pronged approach: assessing and maintaining electrical safety before, during, and after installation. The European Association for Electromobility (AVERE) and the European Electrical Domestic Safety (FEEDS) have collaborated to develop a Safe Electrification checklist, outlining the procedures for the safe installation of recharging points whose findings can be found below:

BEFORE INSTALLATION

CLIENT

- Make sure to ask for a qualified and, where relevant, certified installer.
- Assess your needs as a client (See annexe a) in terms of charging point (Power of recharging point, type of recharging point, AC or DC, and smart or bidirectional recharging point).
- Check with local authorities if a permit is required.
- Check the existence of an electrical inspection report. The report can assess the safety, the readiness to accept new equipment. If no report is available, or if the existing report doesn't give the useful information, it is recommended to ask one if the electrical installation has more than 5 years.
- Check whether the available power reserve of the electrical installation is sufficient to supply the intended car charger; if not:
  - consider, together with the installer, the possibility of improving the load management (either manually or through a load management system) to allow charging of the electric vehicle with the current reserve power,
  - if the previous measure is not sufficient, contact the energy utility/Distribution System Operator (DSO). In this case, it may be necessary to increase the building's connected power or ask for a 3 phases alimentation or provide a new power supply line for the charger from the power grid.
- For shared housing, verify if other tenants/homeowners agree with the necessary works.
- Verify if the area is influenced by fire safety norms.
- Check if and which subsidies are available, and if electrical upgrades are covered.
- Check if any legal permission by interested subjects is required to install.

INSTALLER

- Plan cables paths and ensure all cables from the power source to the charger will have the appropriate cross-section (See annex b) and that all necessary electrical protection devices will be installed.
- Check connectivity: Wi-Fi, Long Term Evolution (LET)/4G/5G (Apps are often required to install the electric vehicle supply equipment and for the management of advanced functions).
- Check socket-type required (Type 1, Type 2, etc.).
- Make sure that the planned recharging point model has a declaration of conformity.
- Execute and release electrical inspection report on the existing installation to ascertain that the existing installation is safe and is prepared to accommodate the new circuit in a safe and efficient way. Especially:
  - Verify electrical panel size and the space availability for new protections like OCPD (Overcurrent Protection Device) and RCD (Residual Current Device), RDC-DD (Residual Direct Current Detecting Device), SPD (Surge Protection Device)... (Depending on the country and the charger model).
  - Determine reserve circuit breaker or space for the installation of one, rated to a nominal current complying with planned charging station power demand.
  - Determine electrical protections that the planned charger model and its configuration will contain.
  - Verify one or three-phase power supply.
  - Control the earthing system.

DURING INSTALLATION

INSTALLER

- Follow the recommendations given by the manufacturer, legal requirements, standards and local specifications.
- Before commissioning the station, measure its power supply installation, confirming the measurements with appropriate protocols that contain in particular:
  - details of the location of the charger and measured installation,
  - qualifications of an electrician performing measurements,
  - earth continuity and its resistance,
  - insulation resistances,
  - voltage drop at the end of the supply line,
  - fault loop impedance and correct operation of all protection devices, in particular RCD.
- Leave enough empty space around the wall box, to prevent overheating and damages because of other electrical appliances.
- Install the wall box at the recommended height and check for norms on accessibility.

AFTER INSTALLATION

CLIENT

- Declare the installation to all relevant counterparties (landlord, condominium administrator, the local fire brigade, the insurance company).
- Ask and keep carefully the documentation provided by the installer, related to the equipment, its installation and legalisation and respect the maintenance plan.
- Never store any combustible materials (Paper, cardboard, paint, wood...) near the electrical board and the charging point.
- Consult an electrician if you observe any electrical problem such as overheating of the cables, deterioration of components, regular blowing of fuses...

Beyond the safe installation of recharging points, it is essential that regular inspections are carried out. The following inspection practices are, according to the FEEDS, deemed good practices:

1. Initial inspection and issuance of a certificate of conformity/inspection report to be added to the technical documents related to the building in order to ascertain correct selection and proper installation of electrical equipment in accordance with national or local regulations.
2. Visual periodic inspection and maintenances actions at least every year by the responsible of the building maintenance/occupant/user to:
    a) Check for visible damage, wear, or signs of vandalism that may have to be addressed
    b) Examine charging cables for signs of wear, fraying, or damage. Damaged cables should be replaced promptly to prevent safety hazards and proper operation of the EV charger
2. A periodic inspection of the installation every 5 years by an approved third-party professional. Depending on the context and local regulations, periodic inspections may be required every year.

The benefits of following inspection practices are:

- Increased safety: regular inspections by qualified experts significantly reduce the risk of fire due to faulty electrical installations.
- Regulatory compliance: Inspections ensure that installations comply with applicable Standards and Regulations.

Beyond electrical issues alone, mechanical protections of the recharging stations should be considered, like bumpers or steel bars.[45] Furthermore, identification of the exact location, type and status of the recharging points in a covered parking lot through information technologies should also help operators of covered parking lots and the emergency services about the nature of fire and how to manage it.
When covered parking lots are equipped with Mode 3 recharging stations, they should be equipped with an emergency power cut-off to isolate all charging facilities in the event of a fire emergency. Based on existing practices, all charging of Mode 3 or Mode 4 should respect the following:

- Emergency isolation points in suitable/practical locations.
- Isolated by “fire alarm’ trip from either smoke detectors, sprinkler system, or both.
- Powered by non-essential service connection.

4.1.3. Standards

In Europe, harmonised product standards cover all safety requirements, including requirements for protection against fire risk such as non-flame propagating

[45] Technical guide "Electric vehicle recharging installations" of the firemen of Barcelona.

products in case of cable management systems. The following is a non-exhaustive list of examples of applicable product standards:

- EV supply stations according to EN IEC 61851-1:2019[46] together with the relevant parts of EN IEC 61439 series and, where applicable, EN IEC 62208:2023.
- EV supply stations according to EN IEC 61851-23:2014 for DC charging stations (mode 4).
- The standard of DC charging station (EN IEC 61851-23:2014.
- Plugs and socket outlets according to EN IEC 62196 series.
- In-cable control and protection device for mode 2[47] charging of electric road vehicles (IC-CPD) according to EN 62752:2016 (under revision[48]) as well as proposing Mode 3 and 4 as best practices.
- Conduit systems according to EN 61386 (all parts).
- Cable trunking systems according to EN 50085 (all parts).
- Cable tray systems and cable ladder systems according to EN 61537:2007.
- Cable ties according to EN 62275:2019.
- Cable cleats according to EN IEC 61914:2021.

4.1.3.1. Existing practices

From the survey conducted by CONSUEL and its findings, several key existing practices emerge. It is imperative to enlist qualified installers for the installation of recharging points and associated equipment, including protective devices and wiring systems. Electrical safety hinges on skilled professionals, thus securing an adequate number of fully qualified individuals capable of correctly installing recharging points is paramount. It may be tempting to quickly train unemployed workers to be able to meet the booming demand, but it is better to invest in and value the traditional education system and seek to attract more students. Furthermore, the installation of recharging infrastructure and their respective devices must adhere to the prevailing standards in Europe and the specific regions where the recharging points are being deployed.

In general, all recharging infrastructure must be safeguarded against mechanical damage caused by vehicles. In order to do so, they could be positioned above ground level on a raised platform or protected by curbs, bollards, or metal barriers. Additionally, the use of extension cables for BEV recharging in public areas should not be allowed.

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[46] EN IEC 61851—1:2019. Electric vehicle conductive charging system—part 1: general requirements.

[47] In some countries Mode 2 is not allowed in public areas.

[48] IEC 62752 is under revision including new safety requirements for domestic socket-outlets as the thermal monitoring inside the plug pins of the IC-CPD which stops the charging if the temperature of the pins reaches 70°C.

4.1.4. OEMs

OEMs should anticipate the fires in the design of cars by developing a special access to a battery pack to create an easy access for fire responders. Manufacturers' emergency response guides can provide sufficient vehicle-specific information to firefighters for disconnecting an electric vehicle's high-voltage system.[49] In order to mitigate the risks of stranded energy at the time of emergency incidents, electric vehicle manufacturers should use the International Organization for Standardization standard 17840 template to present emergency response information.[50] For an effective response from the firefighters at the time of a fire incident, the manufacturers' quick guide should include the following information[51]:

- Fighting high-voltage lithium-ion battery fires;
- Mitigating thermal runaway and the risk of high-voltage lithium-ion battery reignition;
- Mitigating the risks associated with stranded energy in high-voltage lithium-ion batteries, both during the initial emergency response and before moving a damaged electric vehicle from the scene; and
- Safely storing an electric vehicle that has a damaged high-voltage lithium-ion battery.

The fire resistance test outlined in Annex 8E of UNECE Regulation No. 100 sets technical requirements for the safety assessment of electric vehicles (EVs), which should be conducted by the OEMs. The goal of this test is to evaluate the ability of the Rechargeable Energy Storage System to withstand external fire exposure. Meeting this requirement ensures that the driver and passengers have sufficient time to safely exit the vehicle.[52] OEMs can go beyond the minimum fire safety requirements and flammability standards to better address challenges for enclosures, plugs, and sockets used in BEV recharging infrastructure and for electric powertrains and Li-ion batteries.

4.1.5. Fire safe materials

Fire-resistant construction materials should be used in the covered parking lots to enhance fire safety while the garages should be kept free of all combustibles and all general construction elements and must be sufficiently stable and mechanically strong. The French Building code asks for the compartmentalisation of walls by a fire-stop rating of one hour (REI60 if load-bearing, or EI60 if load-

[49] (National Transportation Safety Board of the United States, 2020)
[50] (National Transportation Safety Board of the United States)
[51] (National Transportation Safety Board of the United States)
[52] (Troitzsch, 2022)

bearing).[53] In the case of automated storage, the areas intended for vehicle storage are intersected at least every 1,500 square meters by REI 60 vertical walls. They are intersected horizontally at least every three levels by REI 60 floors. Doors in these walls must be flame-resistant E60C. For two-level car parks, the structure is R60 and the intermediate floors are REI60. [54]In other cases, the structure is R90 and the floors are REI90. Partition walls with other activities or buildings must be fireproof, from REI90 to REI 240 depending on the activity and type of building.[55] Communications between the parking lot and other activities must be via a firewall with E30 doors.[56]

4.1.5.1. Existing practices

While all general construction components must be stable and robust enough to withstand potential vehicle damage, recharging infrastructure demands additional attention. The good practice from France[57] suggests that the structures within the right-of-way of the electric recharging station, and up to 8 meters beyond, must have a minimum fire resistance rating of R 60, with the upper floor rated at REI 60. For two-level car parks, the structure should have an R 60 rating, and the intermediate floors must be REI 60. In other cases, the structure must have an R 90 rating, with floors rated at REI 90. Communication pathways between the parking lot and other activities should be protected by a firewall with E30 rated doors. Moreover, the guidelines in the United Kingdom requires that the exterior wall construction of the covered parking lots in certain types of buildings should comply with statutory guidelines, with façade systems recommended to be classified as Euro class A1 or A2.[58] From the point of BEVs, the recent research showed that the use of ceramifying silicone products in a single battery and battery module interiors is an effective measure to prevent the thermal runaway propagation because ceramifying silicone products acts as barriers and protects up to 1200°C.[59]

4.2. Detection of fires

Implementing robust fire detection measures in parking lots, including detectors, thermal cameras, and video surveillance systems, significantly enhances fire safety. These measures enable early detection and identification of fires, supporting swift evacuation, limiting fire spread, and aiding firefighters in locating and extinguishing fires effectively. Fire detectors, strategically placed throughout

[53] French Building code: order of 25 June, 1980 completed by order of May 9, 2006
[54] French Building code: order of 25 June, 1980
[55] French Building code: order of 25 June, 1980
[56] French Building code: order of 25 June, 1980
[57] French Building code: order of 25 June, 1980
[58] (ARUP, 2023)
[59] (Troitzsch, 2022)

the parking lot, promptly detect smoke, heat, or flames, initiating evacuation protocols and intervention measures. Thermal cameras detect temperature changes, identifying potential fire hotspots, while video surveillance systems provide visual confirmation of fire incidents, aiding in verifying the presence and location of fires quickly. Upon detection, automated alarm systems alert occupants, facilitating safe and efficient evacuation. Early detection and response help contain and suppress fire spread, mitigating damage and reducing the risk of secondary fires. Real-time monitoring and surveillance capabilities provided by video cameras enable firefighters to assess the situation remotely and plan their response accordingly. Thermal imaging technology assists in pinpointing the fire source and identifying potential hazards, helping in the development of effective firefighting strategies.

In short, fire detection measures in parking lots are indispensable for enhancing safety. By enabling early detection and response, these measures support evacuation, limit fire spread, and provide crucial support to firefighters, safeguarding lives and property.

4.2.1. Other Measures

In car parks, the presence of trained security agents can be invaluable in assisting with evacuations during BEV fires and providing essential support to firefighters at the scene. When properly trained, security agents become integral elements in ensuring the safety of occupants and facilitating efficient emergency response efforts. Furthermore, determining where EVs are parked helps the fire service in gaining an initial understanding of the situation at the time of fires. Information systems like e-call and license plate recognition can supply operators of covered parking lots and emergency services with details about the BEV on fire, including its type, status, and location. An overview of other measures for detecting fires is as follows:

a) Early Detection and Response:

Security agents are sometimes present in car parks, allowing them to detect signs of fire or smoke promptly. With proper training, security agents can initiate immediate responses, including activating fire alarms, notifying emergency services, and initiating evacuation procedures to ensure the safety of occupants.

b) Assisting with Evacuation:

Where trained security agents are present, they should be equipped to assist with the orderly evacuation of occupants from the car park. They can provide clear instructions, direct individuals to safe exit routes, and offer assistance to those with mobility issues or other special needs, ensuring a swift and organised evacuation process.

c) Implementing Safety Measures:

Security agents can take proactive measures to mitigate risks and contain the spread of fire before firefighters arrive on the scene. This may involve deploying fire extinguishers to suppress small fires, isolating affected areas, and implementing crowd control measures to prevent panic and facilitate evacuation.

d) Coordinating with Emergency Services:

Security agents should be trained to act as liaisons between occupants and emergency services, providing critical information to firefighters upon their arrival. They can convey details about the location and severity of the fire, identify potential hazards or obstacles, and assist firefighters in accessing key areas of the car park.

e) Crowd Management and Communication:

During emergencies, maintaining calm and orderly conduct among occupants is essential for ensuring effective evacuation procedures. Security agents should be trained to manage crowds, provide reassurance, and communicate important updates or instructions to occupants, helping to minimise confusion and enhance overall safety.

4.2.1.1. Existing practice

The recommendations from the United Kingdom point out that automatic fire detection systems in covered parking lots, especially those with internal or underground BEV recharging areas, are monitored either on-site or by an accredited off-site alarm receiving centre.[60] Specifically, as put forward by the authorities in Spain, if the recharging infrastructure has a power output exceeding 22 kW given that operators should be able to choose to limit charge rates to below this to circumvent additional requirements, the parking lots are equipped with a temperature control system and smoke extraction. This accreditation is provided by an independent third-party certification body.[61] Furthermore, the Luxembourgish regulation requires that the fire detection system must disconnect the power supply to these charging stations when an alarm is triggered.[62] A push button that activates the parking lots general alarm and disconnects the power to the recharging stations should be installed near the recharging stations.[63] In public parking, an emergency stop button for the recharging stations should be located in the parking lot's surveillance room.[64]

4.3. Evacuation

4.3.1. Structural fire measures enabling the evacuation of car parks

Ventilation system

60 (Fire Protection Association, 2023)
61 Technical guide "Electric vehicle recharging installations" of the firemen of Barcelona
62 (l'Inspection du travail et des mines et le Service Incendie et Ambulance de la Ville de Luxembourg, 2017)
63 (l'Inspection du travail et des mines et le Service Incendie et Ambulance de la Ville de Luxembourg)
64 (l'Inspection du travail et des mines et le Service Incendie et Ambulance de la Ville de Luxembourg)

In covered car parks, the presence of various ventilation systems is paramount for evacuating smoke in the event of a vehicle fire. These systems serve as a critical element, providing essential time for individuals present in the parking lot to safely evacuate and enabling firefighters to effectively intervene on the fire scene. Different types of ventilation systems are utilised in covered car parks, each with its unique capabilities and functionalities that are effective for the BEV fires:

a) Natural Ventilation: Natural ventilation systems rely on passive airflow through openings such as vents, windows, or shafts to remove smoke and heat from the parking area. These systems leverage natural forces such as wind and thermal buoyancy to facilitate the movement of air, helping to dissipate smoke and maintain breathable conditions. These ventilation systems are common worldwide. They are typically designed based on some specific opening area, for example 35% in Poland, and 1/20 of floor area in the United Kingdom. The experts involved in the project have not found a scientific justification for those values. However, there is a long history of such buildings and a general feeling that they are overall safe. For small fires (approximately 1,4 MW) the open ventilation worked well in 86, 31% of cases. If the fires grew larger (4 MW or 6 MW), this percentage drop down to 38,79% and 33,31%. In case of a fire representing the 95th percentile of vehicle fires (8,80 MW), the open ventilation gave us satisfactory outcomes for 14,24% of cases. [65]
b) Mechanical Ventilation: Mechanical ventilation systems utilise fans or blowers to actively circulate air within the parking lot, facilitating the removal of smoke and pollutants. These systems can be configured with ductwork and exhaust fans strategically positioned throughout the parking area to ensure effective ventilation and smoke extraction.
c) Smoke Control Systems: Smoke control systems are specifically designed to manage smoke in the event of a fire, typically incorporating both natural and mechanical ventilation components. These systems may include smoke detectors, smoke exhaust fans, and smoke barriers to contain and disperse smoke, preventing its accumulation in critical areas and aiding in the safe evacuation of occupants.

In the event of a BEV fire, prompt activation of ventilation systems is crucial. These systems play a pivotal role in evacuating smoke from the covered car park, creating clear pathways for occupants to exit safely and providing visibility for emergency responders. By evacuating smoke and heat, ventilation systems buy precious time for evacuation procedures to unfold smoothly. They also enable firefighters to locate and address the fire swiftly, reducing the risk of further escalation and facilitating more effective fire suppression efforts.

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[65] Research project OPUS19 No 2020/37/B/ST8/03839 “Wind effects on building fires in a multiparametric risk assessment with numerical modelling” funded by the Poland National Science Centre

In addition to the evacuation of smoke and heat, it is essential that safety lighting and signs are put in place in the covered parking lots to guide the evacuation of the individuals and to enable firefighters to effectively intervene on fire. In this regard, information adapted to the needs of occupants and users by means of instructions, in sufficient number and in places should be ensured where they are easy to read. This information signs should include guidance for responding to fire emergencies. Through these instructions, individuals should also be capable of recognising the alarm signal and understanding practical evacuation protocols and routes.

4.3.1.1. Existing practices

Fire and smoke should not pose a threat to occupants or firefighters on the scene at the time of a fire incident. Therefore, a smoke and ventilation system either natural or mechanical should be available in the covered parking lots. As a good practice, the French Building code requires that each level of parking lots, except those with extensive ventilation, should be divided into compartments of less than 3,000 square meters, or up to 6,000 square meters if equipped with an automatic sprinkler system.[66] Next, sprinklers are effective at controlling fire development within covered car parks, providing water-based fire suppression. When automatic suppression systems are used with mechanical smoke clearance systems, the sequence of operation for these systems must be carefully planned to ensure that the mechanical ventilation system does not delay the activation of the automatic suppression system.[67]

4.4. Propagation control

4.4.1. Space between vehicles and between vehicles and infrastructure

In enclosed car parks, maintaining fire safety for BEVs necessitates specific considerations. According to reports from RISE[68], key good practices to enhance fire safety include:

- Increasing the distance between parked vehicles, achieved through wider parking spots.
- Elevating the ceiling heights of parking garages.

In multi-level open car parks, the potential for fire to spread to another floor through the drainage system exists, particularly in instances of liquid pool fires.

[66] Building code: order of 25 June, 1980 completed by order of May 9, 2006
[67] (ARUP, 2023)
[68] (Hynynen et al., 2023)

These fires can arise from ruptures in petrol or diesel tanks due to external heating, and their extent depends on factors such as the amount of fuel, the incline of the flooring, and adjacent drains. The probability of fire spread in enclosed spaces is influenced by three primary factors:[69]

1. Distance between parked vehicles: Increasing vehicle width reduces the distance between vehicles, thereby intensifying radiation. For instance, widening parking spots from 1.6m to 2m decreases the distance between vehicles from 0.9m to 0.5m, leading to a fourfold increase in radiation. The width of parking spots, typically 2.5m, also affects the distance between parked vehicles.
2. Materials used in vehicle manufacturing: The proportion of vehicle weight contributed by polymer has risen significantly over the years, from 6% in 1970 to 18% in 2020.
3. Ceiling height of the enclosed space: Lower ceilings heighten the risk of fire spread by increasing radiation from the ceiling towards vehicles, and decrease evacuation times, as these times are based on smoke layering remaining above occupant head level for a period of time.

4.4.1.1. Existing practices

As an existing practice, the Slovakian guidelines recommend having no more than three adjacent parking spaces for EVs and charging stations, with the next such group being apart from each other.[70] Additionally, it is a good practice that the recharging infrastructure is placed further away from escape routes.[71]

4.4.2. Structural fire protection measures to limit propagation

Separating fire compartments with fire-resistant walls, doors and gates or fire dampers and bulkheads to separate BEVs from each other are essential for limiting propagation as it helps with the fire protection of ICEVs.[72] Separation refers to the vehicle or group of vehicles, in its entire envelope, is located at a distance equal to or greater than 3 meters (outdoors) or 4.5 meters (indoors) from other vehicles or combustible elements, or is separated by E60 primary barriers in the entire floor height, or a combination of both.[73] Moreover, the covered parking lots should ensure access to removal of BEVs in case of fire. To reduce the chance of the battery reigniting, the BEV that caught fire may need to be

[69] (Hynynen et al.)
[70] ATN_010 Safety aspects of electromobility - Garages in residential and non-residential buildings with parking spaces with infrastructure for electric cars.
[71] ATN_010 Safety aspects of electromobility - Garages in residential and non-residential buildings with parking spaces with infrastructure for electric cars.
[72] Technical guide "Electric vehicle recharging installations" of the firemen of Barcelona
[73] Technical guide "Electric vehicle recharging installations" of the firemen of Barcelona

moved outside the covered car park for monitoring and further extinguishing.[74] Removing the vehicle is not the duty of the local fire and rescue service, so it might be necessary to arrange a contract with a car removal company. If this approach is chosen, the car park's clear headroom must be considered, as it could restrict the types of recovery vehicles that can access the area.[75]

4.4.2.1. Existing practices

As an existing measure from the United Kingdom, recharging bays must be separated by 120-minute fire-resistant concrete or brick walls, or a 60-minute fire wall such as a twin-skin plasterboard wall. This fire separation could enclose three sides of the vehicle bay.[76] Furthermore, combustible or flammable materials, such as storage or waste, must be kept away from BEV recharging infrastructure and other vehicles.[77] Emergency manual isolation of recharging points must be provided to ensure the safe shutdown of equipment in the event of a fault in the main electrical supply.[78] These isolation points should be clearly marked and strategically located for easy access by trained staff and firefighters.

4.4.3. Technical fire protection measures to limit propagation

Automatic fire protection systems play a crucial role in limiting the propagation of BEV fires in covered parking lots. Sprinkler or mist systems are the main technologies considered by the existing EU regulation and recommendations to mitigates the potential impact of such fire incidents.

Sprinkler

Sprinkler systems in covered parking lots utilise heat-activated sprinkler heads connected to pressurised water pipes. Upon detecting elevated temperatures, the system releases water upon the heat source to suppress or extinguish fires. It is widely used for fire protection in enclosed car parks and can often be supplied directly from the water main. Sprinkler systems are also accepted by insurers as a means to enable risk transfer.

Water mist

Another technical fire protection measure to limit propagation is the water mist. Although it uses less water than a sprinkler system, it is usually more expensive in this application than sprinklers because it always needs a dedicated pump and

[74] Technical guide "Electric vehicle recharging installations" of the firemen of Barcelona
[75] Technical guide "Electric vehicle recharging installations" of the firemen of Barcelona
[76] (RSA, 2022)
[77] (RSA)
[78] (Fire Protection Association, 2023)

tank. Water mist systems provide advanced fire suppression by dispersing fine water droplets at high pressure around a detected heat sourced. These droplets rapidly cool the fire, displace oxygen, and suppress flames efficiently. The system can either be triggered by heat sensitive nozzles or other electronic detections apparatus such as smoke, and temperature. It is a suitable alternative to sprinkler systems, especially in existing garages where there may not be enough space for a sprinkler tank as it involves less water and smaller pipe diameters.

Automatic systems' impact on fire

- Rapid Fire Suppression: Sprinkler and mist systems are designed to detect and respond to fires swiftly triggered by heat sensitive nozzles or other electronic detections apparatus such as smoke, and temperature. These systems will act to provide early warning to both occupants and alert emergency responders to the incident. When activated, the system releases water directly onto the fire source, helping to suppress flames and prevent the fire from spreading further. The systems cannot extinguish battery fires but could reduce or mitigate fire propagation.
- Cooling Effect: EV fires often involve high temperatures generated by the vehicle's battery pack. Sprinklers and mist systems can provide a cooling effect by dispersing water onto the heat source, reducing the heat source surface temperature. Meanwhile, water droplets dispersion in the atmosphere surrounding the heat source contains thermal radiation around the car on fire. Hence, automatic extinguishing systems can prevent fire spread from the first vehicle to others and reduce the overall heat raise in the garage. A single car on fire, burning in a controlled manner and without damage to the car park structure, is much more manageable for the fire service.
- Protection of Surrounding Areas: Sprinkler or water mist systems are typically installed throughout a building or facility, including in areas adjacent to parking lots or garages. By suppressing fires at their early stages, these systems help prevent fires in other areas from spreading to vehicles, structures, or other combustible materials in the car park.
- Reducing Toxic Fumes: BEV fires can release toxic fumes and gases, posing risks to occupants and emergency responders. By quickly extinguishing the fire, automatic systems help mitigate the release of harmful substances. Combined with the ability of water droplets dispersed around the fire source area to capture water-soluble gases, they are improving safety for both individuals within the vicinity and emergency personnel.

Based on the limited number of existing studies, automatic extinguishing systems are highly effective fire protection measures that can significantly reduce the impact of all type of vehicle fires by swiftly suppressing flames, cooling heat sources, and limiting the spread of fire and smoke. Their ability to operate

automatically and provide continuous protection makes them invaluable assets in safeguarding property and preserving life in the event of an emergency.
Some jurisdictions in Europe require sprinkler systems in enclosed parking garages, whilst those that meet the code definition of ‘open’ traditionally have not been required to be sprinklered.

- The newest 2023 edition of NFPA 88A, Standard for Parking Structures, requires sprinklers in all parking structures, including open parking garages.
- The 2021 version of the International Building Code (IBC) has also included more stringent requirements that now require open parking garages greater than 4.460 m2 to have a sprinkler system.
- EN 12845:2015+A1:2020 provide the minimum requirements for the design and installation of automatic sprinkler systems.
- Fire hazards similar to “car parks” fall under the classification Ordinary Hazard Group 2 (OH2). A wet-pipe or system should be designed for a water discharge density of 5 mm/min. and an area of operation of 144 m2(dry-pipe system should be designed for 180 m2).
- NFPA 13 provides the minimum requirements for the design and installation of automatic fire sprinkler systems.
- The European Fire Sprinkler Network (EFSN) position paper on sprinkler systems in parking garages states that sprinkler systems can prevent fire spread between vehicles, and that this also applies to BEVs. The design hazard category should remain OH2 under EN 12845, in the absence of evidence that this hazard classification does not provide adequate fire protection.[79]

4.4.3.1. Existing practices

The Dutch fire safety guidelines recommend installation of a sprinkler or water mist in covered parking lots where EVs are parked. [80] As a good practice for the application of sprinklers, the Belgian Code of Good Practice points out that sprinklers should be evaluated in light of the risk associated.[81] These evaluations should take into consideration of the size of the parking covered parking lot, the amount of EVs expected to be parked, the amount of recharging points, whether the parking is compartmented or not, and the type of building (whether residential or not), and the number of floors in the building.[82] Last but not least, it is good to ensure that where automatic suppression systems are used in conjunction with mechanical smoke clearance systems, the order of operation of these systems

[79] (Hynynen et al., 2023)
[80] (van der Graaf et al., 2023)
[81] (Fireforum, 2023)
[82] (Fireforum)

are carefully considered such that the operation of the mechanical ventilation system does not delay the operation of automatic suppression system.[83]

4.5. Fire extinguishing

4.5.1. Methods to intervene on fire

It is important that the emergency responders develop a strategy for the firefighting immediately on arrival, whether offensive or defensive. According to the “Guidelines for fire and rescue services” published by the Norwegian Directorate for Civil Protection in 2021, there are 4 level of risks for fires in lithium-ion batteries. The fires of BEVs in covered parking areas represent the level 3 and the medium to high risk. Extinguishing, containing and suppressing will require appropriate expertise in the form of training in battery fires.

Another important aspect related to the fires of BEVs in terms of determining the method of intervention is the risk of a hydrogen gas cloud explosion. In case of battery thermal runaway, the total amount of vent gas formed can be estimated from 0,6 to around 3,5 l/Ah. The gaseous hydrogen concentration in the gas mixture could be around 25% of the overall gas released. In case of explosion of the hydrogen content in a confined space, the peak blast wave overpressure would end up between 14 – 20 kPa, at a distance of 20 – 50 m and it is function of the distance from the cloud centre for various quantities of hydrogen mixed with air. Liquid fuels such as petrol and diesel are more likely to initiate or contribute to the fire at an early stage such as liquid pool fires than alternative fuels.

On the issue of stranded energy and the possibility of reignition of a battery, if a high-voltage battery is damaged, energy may remain inside any undamaged battery modules and cells, with no path to discharge it. That stranded energy can cause a high-voltage battery to reignite multiple times after firefighters extinguish an electric vehicle fire. Emergency responders have no way of measuring how much energy remains in a damaged battery, and no way of draining that energy, other than such time-consuming methods as allowing a battery fire to burn itself out. Engineers or other specialists can use the battery management system to check for remaining voltage if the system is operational, and some batteries have built-in discharge ports, also for use by specialists. However, the high-voltage battery system can be damaged, preventing access to the battery management system or to the discharge ports.[84]
The following methods (non-exhaustive) are used by firefighters currently:

[83] (ARUP, 2023)
[84] (Hynynen et al., 2023)

1. Using different kind of blankets for covering a fire source in order to avoid the fire spread out to surrounding vehicles or infrastructure
2. Using water or other standard agents for electric vehicle fires. Water does not pose an electrical hazard to firefighters in a BEV fire, but recharging equipment does.
3. Using sprinkler systems help to prevent spreading fire by limiting its spread and temperature, and by reducing the smoke and limiting the fire development until the fire department can intervene. Moreover, if the fire started somewhere other than the battery, the sprinkler system might even extinguish it.

When handling BEV fires, firefighting personnel must always use full safety clothing with respirators. For firefighting personnel, skin absorption will therefore be the only way to be exposed to HF. When the gas mixture from a BEV fire is below lower explosive limit, there will not be sufficient concentration of HF to represent any significant risk to personnel. If personnel have control that the gas mixture is below lower explosive limit, then the HF gases are also likely under control. Normal firefighting clothing will in most cases offer good protection against HF. In the event of extended exposure in spaces with poor ventilation, a splash suit can be used as an extra barrier.[85]

International standards

Post Incident Vehicle Inspection is defined by the international standard SAE J2990. It recommends two inspection stages after a crash or other incident to make certain that the high-voltage system has shut down and is not damaged—one at the incident scene and one at the storage site afterward. The vehicle should remain physically isolated until it has passed inspection. Recommended inspection steps, and what actions to take, are listed in the table below.

[85] (*Guidelines for Fire and Rescue Services: Risk Assessment and Handling of Fire in Lithium-Ion Batteries*, 2021)

Table 1. Postincident inspection steps recommended by SAE J2990.

Step	Action	Notes
1	Inspect for signs of fire or smoldering.	Use thermal camera or infrared temperature probe if possible.
2	Listen for gurgling, bubbling, crackling, hissing, or popping noises from battery.	Sounds can indicate venting of overheated cells or arcing in high-voltage system.
3	If groups of battery cells have separated from battery enclosure, alert responders of potential exposure to high voltage or fire reignition.	Contact equipment manufacturer for depowering recommendations, packaging instructions, and disposal recommendations. If sufficient information is not available, consult latest version of US Department of Transportation/Transport Canada *Emergency Response Guidebook* for lithium-ion batteries (guide 147) or NiMH (guide 171).[a]
4	If vehicle is submerged, do not remove submerged service disconnect, but turn off ignition if possible. Disable vehicle by chocking wheels, placing in park, and removing ignition key or disconnecting 12-volt battery.	Understand that electric vehicles are designed to be safe in water. Small bubbles emanating from vehicle do not create shock hazard. Water damage to electrical components could lead to reignition. Do not store vehicle that has been submerged indoors until high-voltage energy is depowered.
5	Ensure that high-voltage system is disabled.	Refer to manufacturer's emergency response guide or emergency field guide to verify. At a minimum, disable 12-volt system.
6	Examine mechanical integrity of battery system.	Is enclosure ruptured, cracked, punctured, or dented?
7	Inspect for evidence of fire or heat damage.	Signs include smoke residue or heat damage around battery system and burnt odor from battery system.
8	Inspect for evidence of arcing in high-voltage system. Notify tow truck driver of potential hazards and recommendations for isolation.	Carbon traces indicate that isolation of high-voltage system has been lost.
9	Inspect for evidence of external battery leaks. Notify tow truck driver of potential hazards and isolation requirements.	Electrolyte of lithium-ion battery has sweet odor, like ether, that could indicate battery leak. Leaking electrolyte normally creates drops, not puddles.

[a] A new edition was published in August 2020. The guidebook is intended for use by firefighters, police, and other emergency personnel who may be first to arrive at the scene of a transportation incident involving dangerous goods. Available online in English and Spanish.

[74] *Manual disconnects*, also called *manual service disconnects*, are devices such as plugs, levers, or switches that emergency responders can manipulate to disconnect an electric vehicle's high-voltage system. The devices are found in various locations—for example, behind the back seat or near a rear tire—depending on the vehicle make and model.

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SAE J2990 recommends towing a damaged BEV on a flatbed, to avoid generating voltage from the turning wheels. If the vehicle's wheels must be turned—because it has run off the road, for example—its speed should be kept below 8km/h. After being loaded onto a tow truck, the vehicle's structural integrity should be checked. If the vehicle rolls while it is on the tow truck, the inspection steps listed above should be repeated. SAE J2990 states that tow operators should arrange to tow the vehicle to an offsite location where it can be isolated. Once there, the vehicle should be inspected again. It should also be inspected for evidence of internal battery leaks, which could lead to short circuits or loss of high-voltage isolation, and the battery should be examined for loss of mechanical integrity. If airbags have been deployed, further diagnostic steps should be conducted to assess the integrity of the high-voltage system, such as measuring the battery temperature. SAE J2990 recommends two barrier methods for an electric vehicle during storage:

- Separate the vehicle from combustibles and structures by 50 feet on all sides, or
- Create a barrier of earth, steel, concrete, or solid masonry around the vehicle.[86]

Concerning hazard communication, SAE recommends that manufacturers should make emergency response guides available in digital format at any time, accessible through links from a website, and that the information should be made readily available to third parties.

ISO standard 17840 (Road Vehicles—Information for First and Second Responders) is a set of two documents defining the structure and content of the information that vehicle manufacturers provide for emergency responders to vehicle fires or crashes. The Standard was created under the ISO/TC22/SC12 with the key contribution of the International Association of Fire and Rescue Services (CTIF) with the collaboration of the European New Car Assessment Programme (Euro NCAP). This standard provides with the rescue sheet, defines the general content for manufacturers' emergency response guides and defines the labels and colours used to indicate the fuel or energy used to propel a vehicle.[87]

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[86] (National Transportation Safety Board of the United States, 2020)
[87] (National Transportation Safety Board of the United States)

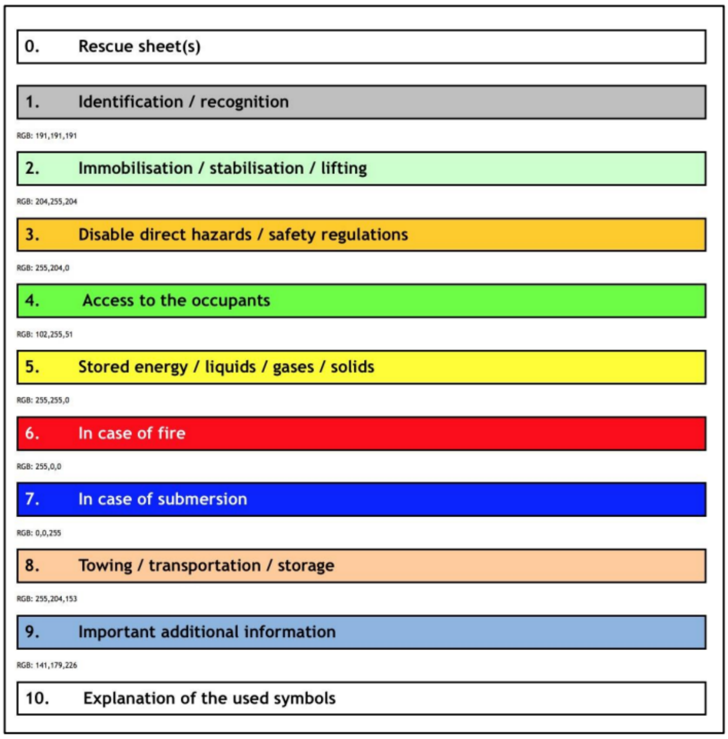

Figure 20. Contents of vehicle rescue sheets and emergency response guides as defined in ISO standard 17840. (Source: CTIF)

Euro NCAP announced in June 2020 that it had centralised the manufacturers' rescue sheets in a free, downloadable mobile application for emergency responders, called "Euro Rescue." In its press release, Euro NCAP stated: "As vehicles have become tougher, more complex and alternatively powered, it has become increasingly crucial that first responders know what they can and can't do at the scene of an accident." [88] This application supports the decision making on energy identification, immobilisation / stabilisation of the vehicle, energy isolation, instructions in the event of a vehicle fire, instructions in case of leaks (gas, electrolyte), instruction in case of submersion, towing instructions, emergency response guides, which should be aligned to the ISO17840 standard. Responders to the fire are then much better positioned to be able to safety interact with the vehicle and its systems.

Furthermore, the NFPA recently added to its website a training video for firefighters, titled "Stranded Energy—How Little You Know Might Shock You."[89] A video prepared for the 2019 North American Heavy Rescue Symposium by the NFPA, and others demonstrates best practices for responding to electric vehicle fires.[90]

[88] (CTIF, 2021)
[89] NFPA Alternative Fuel Vehicle Training for the fire service.
[90] The video demonstrates using a thermal imagery camera to check the temperature of the battery and propping up a vehicle to apply water directly to the battery case. The video was sponsored by the NFPA, the California Department of Forestry and Fire Protection, and the training company Advanced Extrication, with the support of Tesla (accessed June 8, 2020).

4.5.1.1. Existing practices

BEVs are often equipped with emergency cut loops, low-voltage wire loops that first responders can safely cut to disconnect the high-voltage system from the rest of the vehicle. Severing the cut loops will isolate high-voltage power inside the battery, thereby protecting the rest of the vehicle. However, cutting the loops will not remove energy from the high-voltage battery. Manufacturers have developed tools to drain the high-voltage batteries in their vehicles, but the tools, which require a specialist to operate, are usually specific to the vehicle and work only on an intact battery.

5. Recommendations for the private stakeholders and public authorities

5.1. Industry and business stakeholders

- **Emergency Planning**: Businesses should implement comprehensive fire emergency plans for all covered parking facilities.
- **Signage**: Recharging station areas in parking lots must feature visible and appropriate signage.
- **Staff Training and Emergency Response**: Security personnel and other staff should be informed about the location of recharging areas, power isolation procedures, and alarm activation steps. Staff must be trained to safely operate vehicle chargers and report damaged equipment promptly. Defective chargers should be isolated, marked with warning notices, and updated as "offline" in relevant apps.
- **Fire Risk Management**: Parking lots should not store combustible materials or flammable products, refuel vehicles, smoke, or allow open flames.
- **Measures to consider at the installation phase of recharging infrastructure**:
    - **Location**: Install recharging stations near the entrance or exit of underground garages to facilitate quick access for emergency responders.
    - **Qualified Installation**: Only specialised, registered electricians should install charging devices and associated power supplies to comply with legal and technical standards. Non-compliant installations may void insurance coverage.
    - **Protection and Safety**:
        - Protect charging stations from collisions or mechanical damage.
        - Ensure compliance with these minimum standards:
            - Power supply via a central distribution unit, with overcurrent protection and residual current circuit breakers for each charging point.
            - Emergency shutdown buttons installed in secure, accessible locations.
            - Surge protection.
            - Chargers mounted on non-combustible surfaces.

- Clearly labelled kill switches and circuit breakers.

- **Measures to consider for damage prevention**
  - **Fire Alarms and Sprinklers**: Install automatic fire alarms and sprinkler or water mist systems to enhance safety, particularly given the flammability of modern vehicle materials.
  - **Emergency Shutdowns**: Equip parking facilities with automatic and manual emergency shutdown systems for all chargers, operable from a central location such as a fire alarm centre.
  - **Minimise Combustible Materials**: Limit the use of flammable materials or critical infrastructure near charging stations. Walls should have adequate fire resistance (minimum two hours), and passive barriers should be installed to contain fire.
  - **Risk Modelling**: Recharging infrastructure manufacturers should enhance risk modelling and battery performance monitoring to mitigate potential hazards.

- **Measures concerning standardisation and certification**
  - **Infrastructure Standardisation**: Increased standardisation can improve accessibility and reliability of EV recharging infrastructure.
  - **Equipment Certification**: Certification of recharging equipment can enhance reliability and safety for public use.

5.2. Duty of care by the BEV user

- Users of BEVs have a responsibility as well, and they can play their part by treating the devices and cables with care and by avoiding damage by not crushing, shearing, or driving over cables.
- Users should consult user manual instructions regarding battery charging (voltage, current, max charging times, etc.)
- Users should also frequently check the charging cables and charging devices for damage, for instance by carrying out a visual inspection each time before charging. Defective connectors and cables should be replaced immediately.
- Only charging cables approved by the manufacturers and specifically intended for charging electric vehicles may be used. Standard household extension cables, multiple socket strips, or adapters for charging cannot be used for recharging BEVs.
- Damaged, fire exposed, submerged or under recall electric vehicles or vehicles in which the battery may be damaged could pose a particular fire hazard and should therefore never be parked in any parking structure.
- Having a system in place that informs in case of overcharge on the electric line connected to the wall-charger could help prevent fires.

5.3. Recommendations for public stakeholders

5.3.1. Firefighters

- During vehicle fire intervention, firefighters may use different kinds of blankets for covering a fire source to mitigate the fire propagation.
- Firefighters may use towing equipment to move vehicles to open-air environments monitoring the vehicle in case of thermal runaway. However, potential high voltage batteries re-ignition cannot be excluded.
- Maintaining a safe distance, using 1000-volt gloves near batteries and high voltage circuits, is crucial due to the potential exposure of live components during physical damage and fires.
- Using water or other standard agents for BEV fires. However, a high volume of water is one of the solutions to cool-down the high voltage batteries. Water does not pose an electrical hazard to firefighters in an electric vehicle fire. In a safe scenario and after a risk assessment, transport a vehicle outside a parking area and eventually submerge it in a big container (portable) with a water (cooling is the best way to control a fire) if others extinguishing methods are not effective.

5.3.2. Public authorities

- It is recommended that local and regional authorities strongly encourage fire risk assessments for existing infrastructure to ensure a high level of safety for users and minimise the risk of fire.
- These assessments provide an in-depth, objective analysis of existing facilities and offer recommendations for improving safety. They enable progressive action plans to be drawn up, adapted to operators' constraints, to raise safety levels in a structured and effective way.
- Public authorities can help in securing an adequate number of fully qualified individuals capable of correctly installing charging points. They can invest in training unemployed workers to be able to meet the booming demand or invest in and value the traditional education system and seek to attract more students.
- Public authorities should better regulate and enforce the fire safety requirements for enclosures, plugs, and sockets used in BEV recharging infrastructure by raising the minimum fire safety / flammability standards as well as should introduce fire safety requirements and tests for addressing new fire safety challenges for electric powertrains and Li-ion batteries.

6. Conclusion

The rapid growth of BEVs in Europe, spurred by ambitious legislative frameworks such as the Fit for 55 package and the revised EPBD, necessitates comprehensive fire safety guidelines for covered parking areas. Despite existing studies suggesting that BEVs are less prone to fires compared to ICEVs, there is currently insufficient statistical information that enables the adequate assessment of such risks, making the identification of effective measures to ensure fire safety challenging. The increasing prevalence of BEVs and their associated recharging infrastructure introduces new fire safety considerations that must be addressed proactively.

Our analysis highlights several key points:

1. Legislative Support and Infrastructure Development: The Fit for 55 package, along with the AFIR and the revised EPBD, provides a comprehensive legislative framework to support the deployment of BEVs and recharging infrastructure. These regulations mandate significant infrastructural enhancements, particularly in covered parking areas, to facilitate the transition to zero-emission vehicles.
2. Fire Risk Profile of BEVs: Despite concerns, current data suggests that BEVs, particularly those fitted with lithium-ion batteries, have a lower propensity for fire incidents compared to internal combustion engine vehicles. This lower risk profile is partly due to the sophisticated design and engineering of BEV batteries.
3. Harmonised Fire Safety Measures: It was emphasised that harmonising fire safety measures across covered and underground parking spaces in the EU is crucial. Consistent guidelines will help mitigate potential risks and enhance safety standards for BEVs in covered parking lots.
4. Challenges and existing practices to address them: Several challenges and best practices have been identified in terms of fire prevention, fire detection, evacuation, propagation control, and fire extinguishing. Best practices addressed both national, regional, city policy makers for electric vehicles and general recommendations for all types of vehicles; and private stakeholders such as industry and business.

Several future considerations must be addressed to ensure the continued safe deployment of EVs in covered parking areas:

1. Ongoing Risk Assessment and Adaptation: As BEV technology and vehicle designs evolve, continuous monitoring and adaptation of fire safety measures will be necessary.
2. Enhanced Training for Stakeholders: Comprehensive training programmes for parking lot operators, firefighters, and risk assessors are

essential. These programmes should focus on the specific fire risks associated with BEVs and the best practices for managing these risks.

3. Collaboration and Knowledge Sharing: Increased collaboration between public authorities, private sector stakeholders, and international bodies will facilitate the sharing of knowledge and best practices. This collaboration can drive the development of innovative solutions and harmonised safety standards.
4. Integration of Advanced Technologies: The integration of advanced fire detection and suppression technologies in covered parking areas can significantly enhance safety. Research and investment in such technologies should be prioritised to provide robust protection against potential fire incidents.
5. Public Awareness and Education: Raising awareness among BEV users about the importance of fire safety and proper charging practices is crucial. Educational campaigns can help inform the public about the risks and the steps they can take to mitigate them.
6. Policy and Regulatory Updates: Policymakers should remain proactive in updating regulations to keep pace with technological advancements in EVs and charging infrastructure. This proactive approach will ensure that safety standards are consistently maintained at the highest level.

In conclusion, while the shift towards electromobility presents numerous environmental benefits, it also brings new challenges such as a need for adapting fire management practices in covered parking areas. By addressing these challenges through comprehensive guidelines, continuous risk assessments, and proactive collaboration and research, we can ensure a safe and sustainable future for electromobility in Europe.

References

- *Annual report 2022*. (2023). NIPV. https://nipv.nl/wp-content/uploads/2023/05/20230424-NIPV-Factsheet-Jaarrapportage-2022-incidenten-met-alternatief-aangedreven-voertuigen.pdf
- *Annual report 2023*. (2024). NIPV. https://nipv.nl/wp-content/uploads/2024/05/20240416-NIPV-Factsheet-Annual-report-2023-Incidents-with-alternative-fuel-vehicles.pdf
- ARUP. (2023). *T0194 – Covered car parks - fire safety guidance for electric vehicles*. https://assets.publishing.service.gov.uk/media/65bb7b5ccc6fd600145dbe1a/covered-car-parks-fire-safety-guidance-for-electric-vehicles.pdf
- ATN_010 Safety aspects of electromobility - Garages in residential and non-residential buildings with parking spaces with infrastructure for electric cars.
- *Bränder i eltransportmedel under 2022*. Swedish Civil Contingencies Agency. https://www.msb.se/sv/aktuellt/nyheter/2023/maj/brander-i-eltransportmedel-under-2022/?ref=warpnews.org
- *Classification and Definition of Vehicles, UNECE*. Retrieved December 11, 2024, from https://unece.org/transport/vehicle-regulations/classification-and-definition-vehicles
- CTIF. (2021). *200,000 users have downloaded the Euro Rescue app - access to 1400 vehicle Rescue Sheets in 4 languages*. 200,000 Users Have Downloaded the Euro Rescue App - Access to 1400 Vehicle Rescue Sheets in 4 Languages | CTIF - International Association of Fire Services for Safer Citizens through Skilled Firefighters. https://www.ctif.org/news/euro-rescue-app-now-available-download-huge-breakthrough-extrication-all-first-responders
- *De verschillende technieken van laden: Mode 1, 2, 3 en 4 | MobilityPlus (NL)*. (2018). MobilityPlus. https://www.mobilityplus.be/en/blog/the-various-charging-technologies-modes-1-2-3-and-4
- *Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024 on the energy performance of buildings (recast)*. (2024, May 8). https://eur-lex.europa.eu/eli/dir/2024/1275/oj
- Eckstein, M., & Maniscalco, P. M. (2006). Focus on Smoke Inhalation—The Most Common Cause of Acute Cyanide Poisoning. *Prehospital and Disaster Medicine*, *21*(S2), p. 49–55. https://doi.org/10.1017/s1049023x00015909
- *EU classification of vehicle types | European Alternative Fuels Observatory*. Retrieved December 12, 2024, from https://alternative-fuels-observatory.ec.europa.eu/general-information/vehicle-types
- *EV battery fire data*. EV Fire Safe. Retrieved December 11, 2024, from https://www.evfiresafe.com/ev-battery-fire-data

- Fireforum. (2023, October 2). *Code de bonne pratique Sécurité Incendie - Thème: Véhicules Electriques dans les parkings*. https://www.fireforum.be/fr/reglementation/cbp-vhicules-electriques-dans-les-parkings
- Fire Protection Association. (2023). *RC59: Recommendations for fire safety when charging electric vehicles*. https://www.thefpa.co.uk/advice-and-guidance/free-documents?q=RC59%20FIRE%20SAFETY%20WHEN%20CHARGING%20ELECTRIC%20VEHICLES
- French Building code: order of 25 June, 1980 completed by order of May 9, 2006.
- *Guidelines for fire and rescue services: Risk assessment and handling of fire in lithium-ion batteries*. (2021). Direktoratet for samfunnssikkerhet og beredskap. https://www.dsb.no/globalassets/dokumenter/veiledere-handboker-og-informasjonsmateriell/tema/risk-assessment-and-handling-of-fire-in-lithium-ion-batteries.pdf
- Hynynen, J., Quant, M., Pramanik, R., Anna, O., Ying Zhen, L., Arvidson, M., & Andersson, P. (2023). *Electric Vehicle Fire Safety in Enclosed Spaces*. RISE. https://ri.diva-portal.org/smash/get/diva2:1744882/FULLTEXT01.pdf
- IEA. (2023). *Global EV Outlook 2023*. IEA. https://www.iea.org/reports/global-ev-outlook-2023/executive-summary
- Kang, S., Kwon, M., Yoon Choi, J., & Choi, S. (2023). Full-scale fire testing of battery electric vehicles. *Applied Energy*, *332*, 120497. https://doi.org/10.1016/j.apenergy.2022.120497
- L'Inspection du travail et des mines et le Service Incendie et Ambulance de la Ville de Luxembourg. (2017, September 18). *Prescriptions de prévention incendie dispositions spécifiques parkings couverts de plus de 20 véhicules*. https://itm.public.lu/dam-assets/fr/securite-sante/conditions-types/itm-cl-1100-2000/ITM-SST-1506-3.pdf. ITM-SST 1506.3.
- McGlone, C. (2022, October 7). *Safety concerns as unqualified electricians found to be installing EV charge points*. Engineering and Technology Magazine. https://eandt.theiet.org/2022/10/07/safety-concerns-unqualified-electricians-found-be-installing-ev-charge-points
- Mohd, & César Martín-Gómez. (2023). Electric vehicle fire risk assessment framework using Fault Tree Analysis. *Open Research Europe*, *3*, 178–178. https://doi.org/10.12688/openreseurope.16538.1
- Myths and facts about fires in battery electric vehicles. (2022). In *LASH FIRE*. Legislative Assessment for Safety Hazard of Fire and Innovations in Ro-ro ship Environment. https://lashfire.eu/media/2022/09/2022-08_Facts_and_Myths.pdf
- National Transportation Safety Board of the United States. (2020). *Safety Risks to Emergency Responders from Lithium-Ion Battery Fires in Electric

Vehicles (pp. viii, ix). https://www.ntsb.gov/safety/safety-studies/Documents/SR2001.pdf

- NFPA Alternative Fuel Vehicle Training for the fire service.
- *Regulation (EU) 2023/1804 of the European Parliament and of the Council of 13 September 2023 on the deployment of alternative fuels infrastructure, and repealing Directive 2014/94/EU*. Article 2(10, 31, 37). (2023, September 22). https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R1804.
- Research project OPUS19 No 2020/37/B/ST8/03839 “Wind effects on building fires in a multiparametric risk assessment with numerical modelling” funded by the Poland National Science Centre.
- *Risks along the value chain – Part I*. (2023, January 11). Swiss Re Institute. https://www.swissre.com/institute/research/topics-and-risk-dialogues/engineering-and-energy/electric-vehicles-ecosystem-risks-value-chain.html
- RSA. (2022). *Risk Control Guide: Electric Vehicle Charging and Enclosed Car Parks*. https://static.rsagroup.com/rsa/commercial-insurance-products/risk-consulting/electric-vehicle-charging-enclosed-car-parks.pdf
- Sergei Levchik, Hirschler, M., & Weil, E. (2011). *Practical Guide to Smoke and Combustion Products from Burning Polymers* (p. 240). Smithers Rapra.
- Technical guide "Electric vehicle recharging installations" of the firemen of Barcelona.
- Troitzsch, J. H. (2022). Electrical applications in Internet of things and e-vehicles: Passive fire safety needs and solutions. *Journal of Fire Sciences*, 073490412211086. https://doi.org/10.1177/07349041221108643
- van der Graaf , J., Hessels, T., & Rosmuller , N. (2023). *Fire safety of indoor car parks accommodating electrically powered vehicles*. Nederlands Instituut Publieke Veiligheid (NIPV). https://nipv.nl/wp-content/uploads/2023/09/20210715-NIPV-Fire-safety-of-indoor-car-parks-accommodating-electrically-powered-vehicles.pdf
- Vanhaverbeke, L., Verbist, D., Barrera, G., Csukas, M., & Jüriado, R. (2024). *Consumer Monitor 2023 European Alternative Fuels Observatory Country Report The Netherlands*. https://alternative-fuels-observatory.ec.europa.eu/system/files/documents/2024-06/Country%20Report%202023%20The%20Netherlands_1.pdf
- *White Paper: Accidental Electrical Domestic Fires*. (2021). FEEDS. https://www.feedsnet.org/wp-content/uploads/2023/01/FEEDS-accidental-fires-202104.pdf
- Willstrand, O., Amon, F., Rosengren, M., & Bisschop, R. (2019). *Fire safety of lithium-ion batteries in road vehicles*. Rise Research Institute Of Sweden. https://ri.diva-portal.org/smash/get/diva2:1317419/FULLTEXT02.pdf

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