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Fire Safety Precautions and Fire Intervention Techniques for Electric and Hybrid Vehicles

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Abstract

This article discusses fire safety measures for electric and hybrid vehicles and techniques for responding to fires that occur in these vehicles. While the environmental and economic advantages of electric and hybrid vehicles increase the use of these vehicles, they also bring with them fire risks arising from battery technologies. Thermal leaks in these batteries can cause serious fires, and this risk increases significantly during traffic accidents. This situation necessitates the development of new strategies for both vehicle manufacturers and emergency teams. The safety of in-vehicle energy storage systems should be increased as well as public awareness. In addition, effective intervention techniques and preventive policies should be implemented to minimize fire risks.

Keywords: Electric batteries, Fire risk, Fire safety measures, Fire response.

1. INTRODUCTION

Electric and hybrid vehicles have different dynamics than internal combustion engine vehicles, and they also contain some risk elements. With the spread of these vehicles powered by lithium-ion cells, the need for effective legal regulations to protect the life and property of society has increased.

Safety is a key priority for electric and hybrid vehicles, especially with regard to cell technology. In this context, it is vital that battery cells are produced, stored, charged and recycled or disposed safely after use without harming the environment. While many countries around the world have developed standards and certification processes to meet these safety requirements, it is clear that there are many areas where these standards need to be improved and harmonized at a global level.

In our country, municipalities and fire departments are requested to conduct inspections for the installation of electric vehicle parking and charging stations in accordance with the provisions of the "Regulation on the Protection

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of Buildings from Fire"(2007), and to prepare fire department compliance reports in accordance with the inspection [1]. In addition, fire safety training requests are received from businesses that manufacture electric vehicles and have electric vehicle fleets.

When considering the principles of intervention in accidents and fires that may occur in garages, while charging or in traffic, for 100% electric vehicles and hybrid vehicles, and the selection of locations where vehicle charging units will be installed in open and closed parking areas, it is seen that the fire safety measures, especially the Turkish Fire Protection Regulation and other legal regulations related to these issues, do not meet the need. The necessary regulations in the Turkish Fire Protection Regulation regarding parking areas and fuel stations for fossil fuel vehicles are not applicable to electric vehicles. The regulation is inadequate in this regard.

While the market share of electric and hybrid vehicles in our country continues to increase numerically day by day, the low number of fire cases due to the fact that the vehicles and their batteries are new makes the experience of responding to fires and accidents in this regard limited.

2. ELECTRIC AND HYBRİD VEHICLES

Vehicles that use electrical energy to generate kinetic energy are generally called Electric Vehicles (EVs). Electrical energy can be used both as a primary energy source and as a secondary energy source. Vehicles used as a secondary energy source are generally called hybrids. EVs are divided into various types depending on the type of use, frequency, size, color and capacity [2].

“Electric cars” include battery electric and plug-in hybrids vehicles. The difference is that pure battery electric cars do not have an internal combustion engine. In contrast, plug-in hybrids have a rechargeable battery and electric motor, and an internal combustion engine that runs on gasoline. This means that a plug-in hybrid can be driven like a standard gasoline vehicle if the owner has not charged the battery. The battery in plug-in hybrids is smaller and has a shorter range than battery electric vehicles, so over longer distances, the vehicle will switch to running on gasoline when the battery runs out. Since plug-in hybrids usually run on gasoline, they tend to emit more carbon than battery electric cars. However, they generally have lower emissions than gasoline or diesel cars [3]. In the early 2000s, efforts were made to increase the use of small vehicles and EVs and HEAs to reduce fuel consumption. In 2004, the Tesla Roadster was developed by the Californian automobile manufacturer Tesla Motors and launched in 2008. In 2010, Mitsubishi MiEV and Nissan Leaf EVs were launched in various countries such as Japan and America. Since 2012, many electric cars such as Citroen C1, Mercedes-Benz Vito E-cell, REVAi, Buddy, Wheego Whip LiFe, Transit Connect Electric, Tazzari Zero, Smart ED, Mia Electric, BYD e6, Ford Focus Electric, BMW ActiveE, Honda Fit, Coda, Renault Fluence Z.E.. Tesla Model S. have taken their place in the market [4]. The interest in electric and hybrid vehicles has increased the production of these vehicles.

The most popular types of electric cars currently in production include BEV (battery electric vehicle), PHEV (plug-in hybrid electric vehicle), HEV (hybrid electric vehicle) and MHEV (mild hybrid electric vehicle). BEVs are cars equipped with one or more electric motors that operate solely on the energy stored in batteries. PHEVs are cars equipped with an electric motor and an internal combustion engine operating in parallel, depending on the load, and also allow the batteries to be charged directly from the electrical grid. HEVs are vehicles that use an internal combustion engine as the main source of propulsion and an electric motor as an additional source, and MHEVs are vehicles based on a similar solution as HEVs, but use the electric energy mainly to power the electrical devices on the vehicle, relieving the combustion unit [5].

Despite the COVID-19 pandemic causing a 16% global decline in passenger car sales in 2020 compared to 2019, electric car sales have increased following the pandemic. This upward trend is expected to accelerate in the coming years, with an estimated 116 million electric passenger cars on the roads worldwide by 2030 [6].

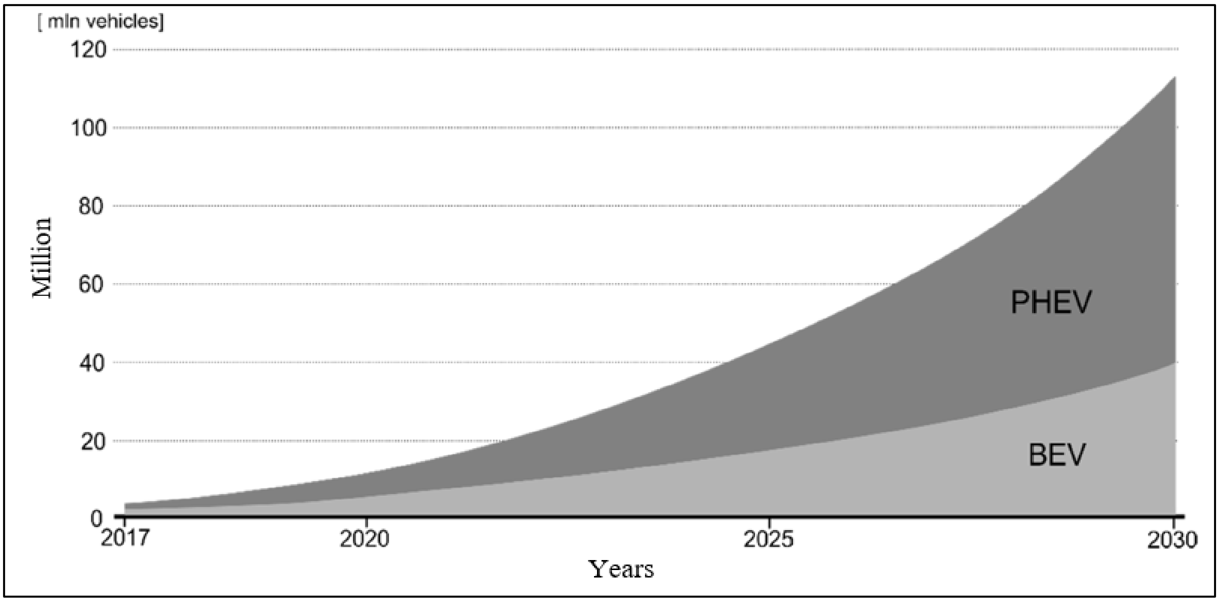

Figure 1. The growth of electric cars in the world, the IEA forecast.

Electric vehicle adoption rates vary significantly across countries (As in Figure 2). These differences can be attributed to factors such as countries' energy policies, infrastructure development capacities, and economic conditions [3].

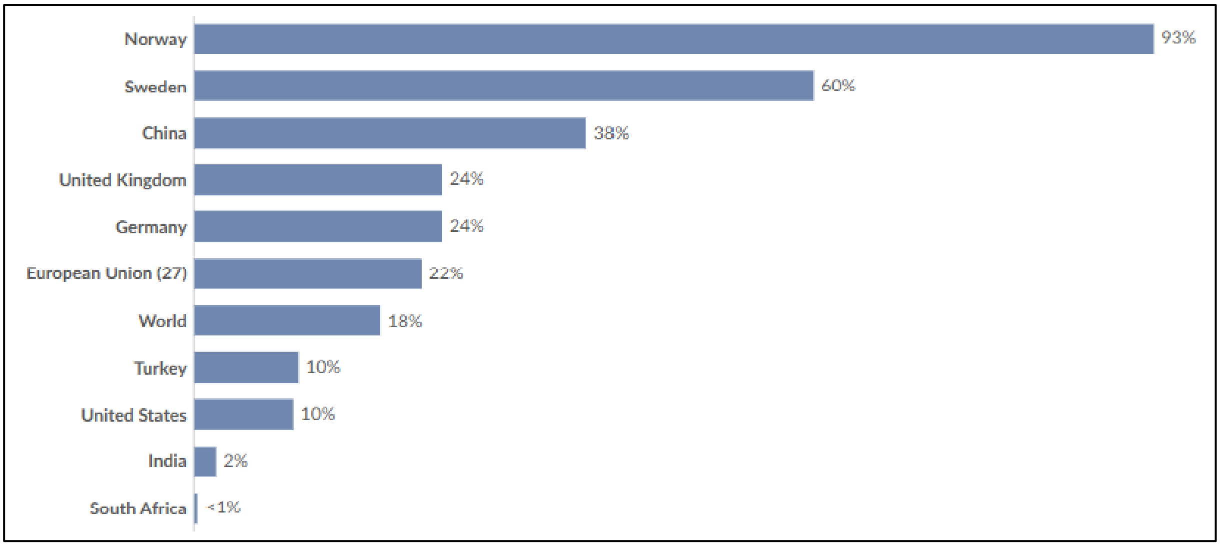

Figure 2. Electric Vehicle Usage Rate % (2024).

Norway is the leader with a 93% electric vehicle adoption rate. This demonstrates the success of Norway's policies towards environmental sustainability goals. Support mechanisms such as tax exemptions, subsidies and a widespread network of charging stations make Norway a leader in this area. Sweden is also at the top with a 60% rate and stands out with its policies supporting the energy transition.

Countries like China, Germany and the UK have a 24% EV adoption rate. While China is one of the world leaders in EV manufacturing and innovation, this rate still has room for improvement given its large population and increasing vehicle ownership. Germany and the UK have strong automotive industries, but the transition is hampered by economic and infrastructural constraints.

The USA comes in the middle-lower levels with 10% and although some states have strong infrastructure, it needs more comprehensive policies and incentive mechanisms at the federal level. In countries such as India and South Africa, electric vehicle usage rates are quite low. India's 2% rate shows the impact of inadequate infrastructure and economic conditions on the transition process. In South Africa, this rate is at 0%, indicating that energy policies and investments have not been sufficiently developed yet.

Turkey stands out with a 10% electric vehicle usage rate. However, this rate is quite low compared to Europe and developed countries. The main obstacles to the adoption of electric vehicles in Turkey are infrastructure deficiencies and economic conditions. The limited number of electric vehicle charging stations and the lack of sufficient domestic production capacity in basic areas such as battery production make it difficult to increase this rate. However, awareness of electric vehicles has increased in Turkey in recent years and positive steps have begun to be taken in line with domestic production targets. In particular, domestic electric vehicle projects and incentive policies indicate that this rate may increase in the future.

When looking at electric and hybrid vehicle sales in Turkey in 2024; 61,73488 vehicles were sold. In electric vehicle sales, Togg ranked first with 30,093 units, Tesla ranked second with 11,534 units, BMW ranked third with 10,173 units, Mercedes ranked fourth with 5,164 units and SSangyong ranked last with 4,0708 units [7].

According to Turkish Statistical Institute data, the number of electric and hybrid vehicles in Türkiye has increased significantly in the last five years. Figure 3 shows the number of fully and hybrid electric vehicles registered in traffic between 2019-2023 [8].

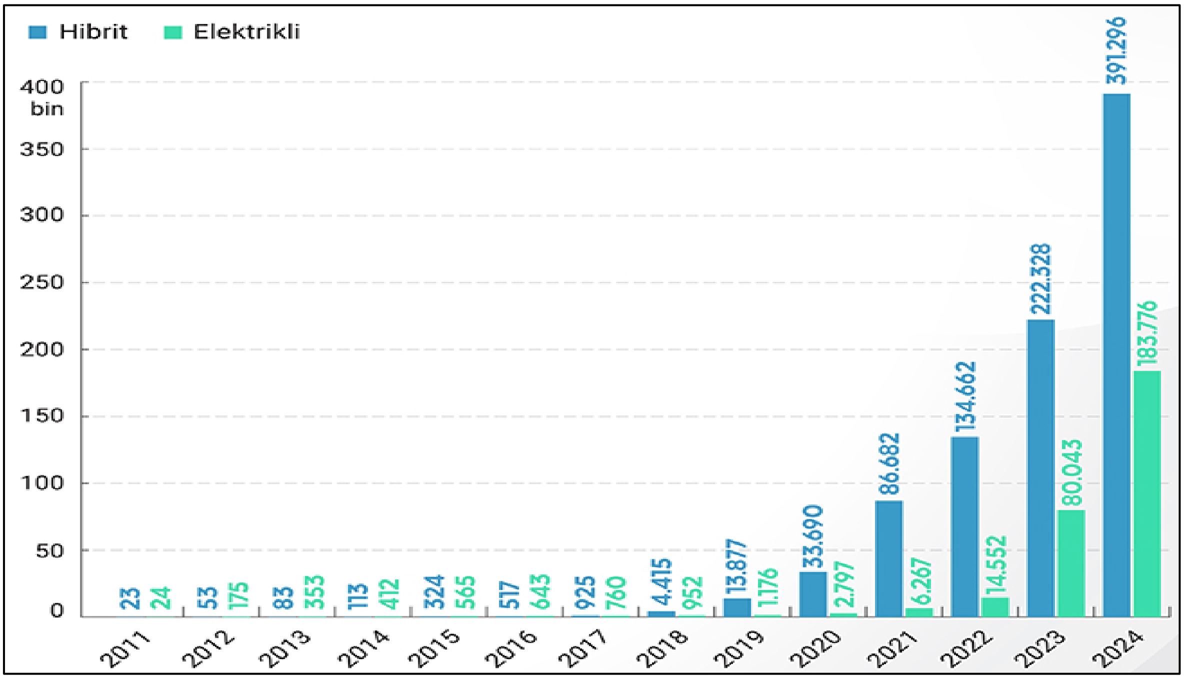

Figure 3. Number of electric cars in Türkiye.

3. CAUSES OF FIRE IN ELECTRIC AND HYBRID VEHICLES

The fact that electric and hybrid vehicles are fully equipped with electrical and electronic systems paves the way for various factors that increase fire risks in these vehicles. In particular, hybrid systems include flammable components such as electric motor and batter, fossil fuel engines and fuel tanks. This situation brings with it risks arising from both electricity and fuel. The most common causes of fires in electric vehicles include battery failures, charging problems, manufacturing malfunctions, external damages and electrical systems. These reasons have an important impact on the safety of electric vehicles and each of them has different risks.

3.1. Battery Failures

Batteries/Cells are systems that convert chemical energy into electrical energy. Lithium-ion batteries consist of four basic components: the positive electrode, the cathode, the negative electrode, the anode, the electrolyte that allows lithium ions to be transported to the electrodes, and the separator that acts as an insulation between the anode and cathode to prevent the risk of short circuits. The cathode part of the batteries consists of metals such as lithium, cobalt, manganese, nickel, iron, aluminum, and phosphate, while the anode part consists of copper, graphite-based carbon, silicon-based carbon, or lithium titanate oxide (Li4Ti5O12), which has been widely used recently. Many of these metals are categorized as flammable solids in the United Nations classification of hazardous substances (Guide classification 4.1, highly flammable, 4.2. spontaneously igniting, 4.3. hazardous substances in wet form). In addition, some of the metals used in the cathode are called flammable solids that produce flammable gases when they react with water or oxygen. The ability of lithium ions to be transported between the anode and the cathode is achieved through electrolyte solution. Electrolytes consist of a mixture of organic solvents and lithium salts. Generally, solvents such as ethyl carbonate, methyl carbonate, propylene carbonate, ethyl methyl carbonate and dimethyl carbonate are used as organic solvents. LiBF4, LipF6 and LiCIO4 salts are used as salts. These solvents used as solvents in the electrolyte are fast-flammable, combustible, and explosive substances that can ignite at very low temperatures. Electrolytes of lithium-ion batteries containing flammable liquids release flammable gases after certain temperatures (> 150°C) and pose a danger when mechanically damaged or overcharged.

Thermal runaway, which occurs in the internal structure of batteries, is considered one of the most critical causes of electric vehicle fires. Thermal runaway occurs when the temperature increases rapidly due to the uncontrolled acceleration of the chemical reactions in the battery and can lead to explosions or fires. Similarly, internal short circuits occurring in battery cells increase the risk of fire by causing the cells to overheat. This situation is usually caused by errors made during production or external mechanical damage to the batteries. In addition, overheating of batteries is another important reason for fires. Overheating during high current draw can lead to deterioration in the chemical components of the battery, which increases the risk of fire.

3.2. Charging Problems

Another common cause of electric vehicle fires is the problems that occur during the charging process. Using the wrong or low-quality chargers can cause batteries to overheat and damage. These devices increase the risk of fire by providing incompatible voltage or current to the batteries. In addition, overcharging batteries can increase the pressure in the cells, leading to thermal reactions and fires. Although modern battery management systems are designed to reduce such risks, faulty chargers or systems can re-introduce this risk. Furthermore, the high energy intake of batteries during fast charging processes causes deterioration in their chemical structure, increasing the risk of fire.

3.3. Production Errors

Errors in the battery manufacturing process can also contribute to electric vehicle fires. Improper placement or assembly of battery cells can lead to internal short circuits and overheating, which negatively affects the performance and safety of the battery. Inadequacies in cooling systems prevent the proper distribution of heat in batteries and increase the risk of fire. In addition, the use of low-quality materials in battery manufacturing increases the risk of fire by weakening the chemical resistance and battery safety.

3.4. External Damage

External damage to electric vehicles, especially when it causes physical damage to batteries, significantly increases the risk of fire. Punctures or crushing of batteries during vehicle accidents can cause short-circuiting of internal components. Such physical damage seriously threatens the structural unity of batteries. In addition, external pressures or impacts on batteries cause structural deterioration, further increasing the risk of fire.

3.5. Electrical Systems

The complex electrical systems of electric vehicles contain several potential problems that can increase the risk of fire. Insulation faults in electrical cables or looseness at connection points can cause short circuits and consequently overheating. This situation significantly increases the risk of fire in electric vehicles. Similarly, electrical components used in the vehicle may tend to overheat in case of overload. Such overloads endanger not only the system components but also the overall safety of the vehicle.

Inadequate protection systems in electrical systems further increase the likelihood of faults turning into fires. In particular, the lack of systems that will quickly detect and isolate short circuits increases fire risks. Therefore, the safe design of electrical systems and the effectiveness of protective mechanisms used in these systems are of critical importance for electric vehicle safety.

In order to minimize fire risks, reliable insulation materials should be used in vehicle electrical systems, connection points should be checked regularly, and effective protection mechanisms should be developed against overload situations. Such measures both increase user safety and contribute to the sustainability of electric vehicle technologies [9-15].

4. FIRE INCIDENTS IN ELECTRIC AND HYBRID VEHICLES

Vehicle fires are considered as one of the major risks surrounding electric vehicles. In this context, a fire incident involving a Tesla Model S, one of the first mass-produced electric vehicles, occurred on a highway in Washington State on October 2, 2013. The cause of the fire was reported as a metal part directly contacting one of the 16 lithium-ion battery modules located under the vehicle (Figure 4a). This incident, along with two other electric vehicle fires within a month, marked the beginning of a series of notable fire incidents. In the last week of October 2013, a second incident occurred in Merida, Mexico, when the driver of a Tesla Model S lost control of the vehicle and crashed into a tree, causing a fire. Approximately two weeks later, a third Tesla Model S fire occurred in Smyrna, Tennessee, when the driver hit a towbar, causing damage to the cover of the power battery modules (Figure 4b). None of these fires resulted in death or serious injury. However, these incidents once again highlighted the critical importance of ensuring the safety of lithium-ion batteries used in electric vehicles [5].

Figure 4. Mass-produced battery electric vehicles (Bev) Jayne first of (a) October 2, 2013, (b) 7 November 2013.

The increase in the number of electric vehicles has led to the risks of vehicle fires becoming more apparent. In particular, it was observed that majority of the fires that occur in thermal energy storage batteries are caused by the battery power system. Fire safety in vehicles is largely related to fuel sources. Gasoline and LPG, which are widely used in fossil fuel vehicles, can be extremely dangerous if not stored or transported safely. Lithium-ion (Li-ion) batteries, which most electric vehicles use as energy sources today, pose greater and various safety risks.

There are some notable features of burning Li-ion batteries. In addition to thermal runaway events, these features include the release of flammable, explosive and toxic gases [16-17]. It is known that when Li-ion batteries catch fire, ambient temperatures can reach very high degrees [13]. This poses a significant risk not only for vehicle users but also for response teams.

The increase in electric vehicle production and sales has naturally led to an increase in electric vehicle fires. Table 2 provides data on electric vehicle fires in six different countries. These data provide a critical framework for understanding how fire risks may differ regionally and the measures that need to be taken to manage these risks more effectively [18].

According to the data of the American NTSB (National Transportation Safety Board); the fire probability of electric battery vehicles is 0.03%, 1.5% for vehicles with internal combustion engines, and 3.4% for hybrid vehicles. This situation was also calculated as 0.0244% for electric vehicles in the research on the fire risk assessment framework in electric vehicles on the official website of the European Union. Although these studies show that fully electric vehicles have the least risk of fire, these statistical data can be misleading because most electric vehicles are still new and it is unclear what kind of result we will encounter as the vehicles age [19].

Table 1: Numbers of Different Countries in Electric Vehicle Fire Table.

Country	Year	Number of Fire EA
Denmark	2018	3
	2019	10
	2020	18
Korea	2017	21
	2018	21
Netherlands	2020	71
	2021	118
Norway	2016	17
	2017	28
	2018	8
	2019	18
	2020	24
	2021	32
	2022	24
Sweden	2018	8
	2019	6
	2020	20
	2024	23
	2022	24
Finland	2015	1
	2016	2
	2017	0
	2018	3
	2019	3

5. FIRE SAFETY MEASURES IN ELECTRIC AND HYBRID VEHICLES

In order to be able to provide opinions and suggestions on what fire safety precautions can be taken on the subject and how to intervene in emergencies, it is necessary to know first of all which chemicals are in lithium-ion batteries and what kind of dangers they contain. Fires that occur as a result of punctures, thermal leaks or short circuits in batteries develop very quickly and take longer to extinguish/cool than other fire classes. The valuable experiences gained by local fire departments regarding the difficulties and possible risks encountered during the fire and accident response stages should be taken into account, and procedures should be established for what kind of fire safety precautions should be taken and how to intervene in fires and accidents by foreseeing other hazards that have not been experienced yet but have the potential to occur.

In all fires that occur in closed spaces, the hazardous chemicals (suffocating, poisoning and corrosive, etc.) released pose risks depending on the type of flammable substance. However, the biggest threat of lithium battery-powered devices is that they contain all of these dangers and all of them occur in the environment at once. This is a very serious risk and this threat should be eliminated as soon as possible. These toxic gases that accumulate in the environment cause loss of life even in a short period of time. The removal of the potential danger as soon as possible and the termination of the incident with the least damage are directly related to the fire safety measures which should be taken. It is very important to detect fire early and take necessary precautions accordingly. Emergency teams should use their time wisely while performing rescue and infection prevention efforts. The activation of ventilation systems that will save time in rescue and evacuation of toxic gases before they accumulate in the environment, the activation of automatic extinguishing systems, and the alarm system informing the occupants and initiating the evacuation will significantly reduce the risk of loss of life and property. At the same time, early warning systems make a significant contribution into shortening the time it takes for local fire departments to arrive at the scene.

According to the experiences gained from the incidents, the biggest risks of battery fires occurring in closed spaces are loss of life due to toxic gases and the rapid growth of the fire and its spreading to other flammables due to high temperature and rapid combustion, in other words, the spread and geometric growth of the fire are very fast. In order to minimize the damage caused by these two risks, it is very important to determine the points where the charging stations will be installed and the fire precautions to be taken. It is best to install vehicle charging stations in open areas and in places where the live load is low in terms of safety. If they are to be installed in closed areas, then it is necessary for these areas to be chosen in ground floors where the discharge of the gases that will be released will be easier, and for these areas to also be close to the exits on the ground floors.

The Regulation on the Protection of Buildings from Fire, which was issued on 27.11.2017, in order to determine the procedures and principles regarding the measures, organization, training and inspection that must be taken before and during fires in order to minimize the fires that cause loss of life and property in all kinds of structures, buildings, facilities and businesses used by public institutions and organizations, private organizations and real people in Turkey.

The fire protection regulations regarding detection, extinguishing and ventilation in parking lots were created considering fossil fuel vehicles. Since the batteries of electric and hybrid vehicles consist of many flammable, especially toxic gases and corrosive chemicals that react with water or other liquids in case of fire and leakage, it is essential to evacuate these dangerous chemicals that will accumulate in closed areas as soon as possible. In the new regulation to be made, ventilation and extinguishing systems in all closed vehicle parking lots, regardless of the square meter size of the parking lots, should be rearranged taking these dangers into consideration. Recently, there have been accidents as a result of fires involving electric bike and car batteries. Mainly bicycles and scooters, which are widely used, are charged in closed areas in homes and workplaces. This situation, which does not have any restrictions on taking them into land, sea and rail public transportation vehicles, has led to loss of life in the fires that have occurred.

According to Article 96/c of the Turkish Fire Protection Regulation, indoor car parks with a total area exceeding 600 square meters shall be equipped with a sprinkler system (automatic sprinkler system) [20]. This article needs to be revised as an automatic sprinkler system should be installed in all structures categorized as indoor car parks regardless of their square meter size, taking into account the flammability characteristics of the battery contents of electric vehicles and the speed of fire spread. In addition, for electric cars, the sprinkler system should not be installed on the ceiling; since lithium-ion batteries are located at the base of the vehicle, sprinkler heads should be designed to be placed on the ground and in a protected area where these vehicles will park and charge.

Regarding ventilation, according to Article 60/2 of Section 5 of the Turkish Fire Protection Regulation, it is mandatory to have a mechanical smoke exhaust system for indoor car parks with a total area exceeding 2000 square meters. This system should be designed to be independent from other ventilation systems serving the building, and to perform 10 air changes per hour. Compared to fossil fuel vehicles, lithium-ion batteries that form the fuel energy of electric vehicles release toxic and flammable gases in the event of fire or thermal leakage [21]. In case of inhalation of these gases, it is inevitable to experience losses due to poisoning even in very short periods. In this article, the hourly capacity power of the ventilation systems should be increased by at least fifty percent regardless of the square meter size of the indoor car parks where electric vehicles are charged and parked.

In accordance with the fourth paragraph of the same article, the ventilation and electrical systems of the parking lots where LPG vehicles will be located must be spark-resistant (ex-proof), and the ventilation system shall be automatically operated and connected to a device that detects LPG gas accumulated at ground level and shall have the capacity to sweep the gas. The accumulation of flammable and explosive gases such as Ethylene (C_2H_4), propylene (C_3H_6) and Ethane (C_2H_6) must be taken into account. Toxic and corrosive chemicals such as sulfuric acid (H_2SO_4), potassium hydroxide (KOH), hydrofluoric acid (HF), hydrochloric acid (HCl), and lithium hydroxide (LIOH), which are emitted from organic solvents used in electrolyte solvents in batteries, must also be taken into account. Last but not least, the risk of accumulation of heavier-than-air and lighter-than-air gases accumulating in the bottom and in the air in case of leaks, must be taken into account as well.

In category C, indoor car parks where LPG vehicles can be accommodated cannot be located on floors lower than the 1st basement floors, and these car parking spaces and their entrances and exits are arranged separately from parking spaces where other vehicles and their entrances and exits can be accommodated.

In case of all-electric or hybrid vehicle fires; considering the risks to human health caused by the explosive and toxic chemicals accumulated in the environment, the difficulties in responding to the fire, the rapid geometric growth of battery fires over time, and the need to move the vehicle to a safer area due to the possibility of fire spreading to other vehicles and flammable materials, independent parking areas for only electric vehicles should be planned in places close to the entrances and exits of the parking lots and ground level. Charging units should be placed in open areas if possible. Otherwise in places designed as electric vehicle parking spaces, taking into account the above criteria. In addition, attention should be paid to the isolation distances to other parked vehicles in this area to be of at least three meters in all directions.

6. ELECTRIC VE HYBRID VEHICLE FIRES INTERVENTION TECHNIQUES

Compared to extinguishing fires in electric vehicles and other fossil fuel vehicles, more extinguishing agents are needed because the cooling period takes a longer time. The determining factor in fire response is the type of flammable material. The danger posed by the fire, the speed and intensity of the combustion and the determination of the isolation distance are the most important parameters in the selection of protective equipment and the type of intervention [21]. In terms of combustion products; when electric vehicle batteries burn, toxic chemicals such as sulfuric acid, potassium hydroxide, hydrogen fluoride, phosphorus pentafluoride, carbon monoxide and lithium hydroxide (LiOH) that affect both the skin and the respiratory system are released. These chemicals cause serious health problems by penetrating the skin and respiratory system. They cause death by causing edema in the lungs and poisoning. The solvents that make up the electrolyte are considered very good flammables due to their chemical structure and they cause a sudden increase in temperature in closed areas. This causes the fire to spread to other flammable materials in a very short time and increases the fire geometrically [11].

Fire risk in electric and hybrid vehicles is a significant problem, especially for BEVs (Full Electric Vehicles) and PHEVs (Rechargeable Hybrid Vehicles) with large battery capacities. The dense structure of batteries in such vehicles makes it difficult to effectively extinguish a fire. Researches have shown that re-ignition events frequently occur hours after a fire is extinguished in vehicles consisting of Li-ion battery modules. For example, it has been reported that a re-ignition occurred 22 hours after a fire was extinguished in a battery module consisting of 288 cells [22-23].

How should lithium-ion battery fires be intervened and which extinguisher should be used as an extinguishing agent is currently an unknown issue. When the content of the battery's anode, cathode, electrolyte and other components is examined, it is found that it is composed of flammable metals, salts, organic solvents and plastic materials. The elements that make up the battery are lithium (Li), graphite (C), nickel (Ni), manganese (Mn), iron (Fe), cobalt (Co), aluminum (Al), copper (Cu) and phosphate (PO4) such as aluminum hydride. The electrolyte solution is a mixture of solvents and lithium salts. The substances that make up the cathode part of the battery are classified as class 4 flammable solids and class 9 miscellaneous hazardous materials in the Hazardous Materials Identification Guide (2014) [24]. The way these metals burn, the health effects of the hazardous chemicals released when they react with fire or water, the isolation distances in large and small spills, and the method of intervention in fires are specified. The guide numbers of the chemicals that make up the battery content are classified as 125, 138, 147, 154, 157.The Hazardous Substances Identification Guide (2014) states that these metals when in contact with water produce flammable gases and create violent explosions, and that corrosive and toxic gases/liquids are formed as a result of combustion or when they react with water. It is also stated that they have the ability to re-ignite after being extinguished. For public safety, first create an isolation distance of 25 meters to 50 meters in each direction and 250 meters to 800 meters depending on the size of the fire.

Due to the heat released and high temperatures generated in fires, foam agents used in extinguishing lose their cooling effects as their chemical structures decompose at these high temperatures. Compounds such as lithium hydroxide (LiOH) or lithium carbonate (L2CO3), used as cathode materials in lithium-ion batteries, decompose into lithium, hydrogen and oxygen elements and create a fire-inducing effect when the heating occurs in the battery and the combustion reaction starts. In other words, it produces Hydrogen as the flammable substance required for combustion and Oxygen as the oxidant. For this reason, one of the extinguishing methods of lithium-ion battery fires, the oxygen-free extinguishing method, is not effective. Insulating foam agents are produced for lithium-ion battery fires, but detergents that do not lose their extinguishing effect at the high temperatures that occur are not currently available. Detergents and other extinguishing agents used by fire departments to extinguish fires also fail to provide effective cooling for the same reasons. Among the extinguishing agents, water is considered cheaper and easier to access and is widely used to extinguish electric vehicle fires compared to other extinguishers.

When electric and hybrid vehicle fires are compared to other fossil fuel vehicle fires; much more hazardous chemicals that negatively affect health and the environment are released as combustion products. In addition, the temperatures and heat energy released in electric vehicle battery fires are higher than in fossil fuel vehicle fires. The process of controlling fires and cooling them to a level where they cannot be re-ignited also takes longer, and the amount of extinguisher used for cooling is much higher than in other vehicle types. For example; in the event of a 75 kWh NMC532 vehicle battery burning, the nominal value of the heat energy released is calculated as 270,000,000 joules (1 kWh = 3600 Kj). However, due to the oxidation of other combustibles that make up the content of lithium batteries, this energy can be 2 to 5 times more. The energy that will be released in the event of combustion of a lithium-ion battery of this size can be between 540 Mj and 1350 Mj. If we take the average of these two values, a heat energy equivalent to approximately 1000 Mj is formed. In order to completely cool this amount of heat energy (to reduce it below the ignition temperature), the water consumption to be used in cooling will be quite high.

It is possible to increase the cooling feature of water to higher rates and to reduce the amount of water used in extinguishing to much lower levels. The heat required to completely convert water into vapor at its boiling point is called the heat of vaporization (Lb). The amount of heat that must be given to turn m grams of water into vapor at a constant temperature is calculated with the formula Q=m.Lb. The heat of vaporization of one liter of water at 100°C at one atmospheric pressure is 540 call/gr (Enthalpy of vaporization). In joules this is approximately 2260 joules. The energy required by firefighters to heat one liter of water from 20°C to 100°C is 335 joules (80x4.186). When one liter of water used by firefighters to completely extinguish a fire evaporates, it absorbs 2,595 thermal energy from the environment. When we convert the heat energy emitted from the burning battery into the vapor phase by taking advantage of the ability of water to evaporate and remove heat from the environment, the heat generated on and around the battery will be removed from the center of the fire. Thus, when the heat drops below the ignition temperature that helps combustion, the fire can be brought under control. In a cooling and extinguishing intervention performed with this method, in a closed area combustion scenario of a lithium NMC532 battery weighing 450 kilograms and having a capacity of 75 kWh, the heat energy released in the first 25 minutes can exceed 1600°C at the center of the fire. These indoor temperatures not only prevent intervention by non-professionals other than firefighters, but also make intervention by firefighters difficult. Cooling efforts with traditional intervention methods cause a large amount of water to be consumed. In fully electric car fires that have occurred in the world and in our country to date, the amount of water used in extinguishing is an average of 30 thousand liters [25]. The main reason why the amount of water used in extinguishing is so high is that the water directly applied to the fire flows away without evaporating.

Instead of the 16 bar pumps commonly used by fire departments in fire extinguishing, the use of pump systems that break water at high pressures (200 bar) and reduce the size of water droplets to a much smaller size in millimeters will further reduce the amount of water to be used in cooling. If we assume that water droplets are broken with high pressure compressor systems, and the lance systems to be used in for intervention are adapted accordingly, assuming that the water is used effectively, the thermal energy released from the battery (1000 megajoules = Msu × 2595 joules) can be calculated from the formula (msu = 385.356,455 grams). This corresponds to approximately 386 liters of water [5].

In cases where the battery is negatively affected after electric and hybrid vehicle fires or vehicle accidents, the vehicle must be transported to a safe area using pool-tank systems where it will be submerged in water after the intervention. The safest form of intervention would be to keep the cells submerged in water until the heating and gas emissions in the cells are completely eliminated. However, there is a risk that water can damage electronic components and react with lithium to release hydrogen gas. In this context, innovative approaches such as boron-based extinguishing agents or Novec 1230, which offer environmentally friendly and effective solutions, have been developed [26-27].

Internal fire prevention systems installed in vehicles to prevent the spread of thermal runaway can detect temperature increases at an early stage using sensors and prevent the fire from growing by applying a local cooling agent. While external systems are effective in limiting the risk of thermal runaway by cooling the area around the battery, internal systems are more successful in preventing battery-related fires [28]. In addition, if batteries are not cooled, the risk of flammable gas release increases. If gases accumulate in closed areas, the risk of a fire re-igniting increases significantly.

When flammable metals (lithium, aluminum, cobalt, manganese, nickel, iron, copper), which are other important components of the battery, participate in the combustion reaction, very high temperatures occur and it becomes even more difficult to extinguish the fire. Especially in closed environments, the sudden increase in temperature and the accumulation of toxic gases are very risky for both the responders and the trapped [29]. In such cases, the environment should be left as soon as possible. People who will respond to the fire or accident should also use protective clothing against heat and chemicals and closed-circuit breathing systems due to these dangers. In addition to these, in rescue operations for electric vehicle accidents, aside from fires, it is also necessary to use spark-free equipment to prevent ignition risks and insulated gloves to protect against electrical shocks. It should also be known that heat-resistant protective clothing provides limited protection against toxic chemicals emitted from the battery in electric vehicle fires. It is also necessary to wear Class A chemical protective clothing against chemical gases that might penetrate through the skin.

In electric vehicle fires, it is recommended that firefighters use self-contained breathing apparatus (SCBA) due to harmful hydrofluorocarbon emissions. It has been stated that teams without SCBA equipment should not approach the fire closer than 15 meters [5]. The increase in the number of electric vehicles has increased the difficulty of extinguishing operations and has led to the need to develop safety protocols in this area. Training of extinguishing teams in accordance with these new conditions is critical to ensuring fire safety [27].

The issue of which effective cooling methods should be used to extinguish fires in electric and hybrid vehicles, and how to use them, is still in the conceptual stage. One of the ideas considered is to have inflatable barriers in the fire department vehicle equipment and to create a barrier around the vehicle and fill it with water (so that the battery remains in water). This method is applicable and more attractive in terms of cost than other vehicle-top tank pool systems. It can be applied more easily, especially when dealing with vehicle fires in closed areas.

The path to be followed regarding the intervention in electric vehicle accidents and fires has not yet been determined. Even if the batteries are not damaged in vehicle accidents and a fire does not break out, it is highly probable that this risk will occur within the next few days. The same situation continues for the first 72 hours after the fires are extinguished. Post-intervention procedures should be established urgently. In addition, it is very important to determine which institutions and organizations will be qualified for removing debris from the scene and recycling it through legal regulations.

As a result, when electric and hybrid vehicle fires are compared to other fossil fuel vehicle fires; much more dangerous chemicals that negatively affect health and the environment are released as combustion products. In addition, the process of controlling the fires of these vehicles and cooling them to a level where they cannot be re-ignited takes more time, and the amount of extinguisher used for cooling is much higher than other types of vehicles. For example; in the event of a 75 kw vehicle battery burning, the amount of water to be applied in the extinguishing to eliminate the heat energy released is approximately 30 tons (75 kw = 270,000 kJ, 1 liter of water. In cases where the battery is negatively affected after electric and hybrid vehicle fires or vehicle accidents, the vehicle must be transported to a safe area using pool-tank systems where it will be submerged in water after the intervention. The safest form of intervention would be to keep the cells submerged in water until the heating and gas emissions in the cells are completely eliminated.

7. CONCLUSION

This study comprehensively covers the risks and intervention techniques for electric and hybrid vehicle fires. Research has shown that electric vehicle fires can grow very quickly in closed areas and extinguishing these fires can take longer than traditional methods. This necessitates the development of special solutions and techniques in terms of fire safety. Placing charging stations in open areas or on ground floors equipped with ventilation and security systems will significantly reduce fire risks. At the same time, the widespread use of automatic fire extinguishing systems and early warning mechanisms plays a critical role in controlling potential hazards.

Training of emergency teams for fire response operations is of great importance in terms of effective management of such incidents. Response teams must be equipped with appropriate equipment against harmful gases and high temperatures released during fires. In addition, the effectiveness of extinguishing agents used should be increased in order to prevent sudden explosions that may occur as a result of chemical reactions and to prevent the geometric growth of the fire. The study stated that environmentally friendly solutions such as boron-based extinguishing agents and Novec 1230 offer an effective alternative in fire response cases.

As a result, a comprehensive approach is required for the prevention and management of electric and hybrid vehicle fires. This should include both vehicle design measures and legal regulations. At the same time, raising public awareness on this issue will encourage the safe use of electric vehicles and lay a more sustainable foundation for the widespread adoption of these technologies.

Authors' Contributions

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1- Study design 2- Data collection 3- Data analysis and interpretation 4- Manuscript writing 5- Critical revision			

References

[1] The Regulation on Fire Protection Of Buildings (2007). Official Gazette (6.735). Ministry of Public Works and settlement
[2] Batuhan, I. (2022). Electric vehicles, electric charging stations, and Turkey for the period the amount of estimated future electric vehicle. (Master's Thesis). Higher education Institution thesis retrieved from the database. (Thesis no: 741220)
[3] Ritchie, H. (2024). Global tracking data pre-electric vehicles. Published online at OurWorldinData.org. URL: https://ourworldindata.org/electric-car-sales (access date: 10.01.2025).
[4] Yıldırım, M. (2022). Safety measures in electric vehicles. (Ph. D. Thesis).Higher education Institution thesis retrieved from the database. (Thesis no:712691).
[5] Dorsz, A., & Lewandowski, M. (2022). Analysis of fire hazards associated with the operation of electric vehicles in enclosed structures. Energies, 15(1), 11. https://doi.org/10.3390/en15010011
[6] IIEA. (2021). Global EV Outlook 2021. Paris, France: International Energy Agency. URL: https://www.iea.org/reports/global-ev-outlook-2021(access date: 10.01.2025).
[7] Ozbugut A. C., & Yılmaz, E. (2024). 100 thousand electric cars were sold in 2024. URL: https://www.aa.com.tr/tr/ekonomi/2024te-100-bine-yakin-elektrikli-otomobil-satildi/3444453(access date: 10.01.2025).
[8] TÜİK. (2024). 2024, The number of electric vehicles in Turkey. The Target Fleet. URL: https://ev.hedeffilo.com/evgundem/blog/2024-yilinda-turkiyedeki-elektrikli-arac-sayisi
[9] Kazak, D. (2024). Lithium-ion batteries in fire safety: all-electric vehicles in risk assessment, prevention and fight. Premium e-Journal of Social Sciences (PEJOSS), 8(42), 638-652.
[10] Alyar, H. (2022). The structure of electric cars and fire risks. International fuels and combustion, Fire Journal, 10, 1-8. https://doi.org/10.52702/fce.1057432
[11] Karamangil, M. I. Riding, A., & Thompson, M. (2022). A review of battery fires in electric cars. International fuels and combustion, Fire Journal, 11(1), 29-40. https://doi.org/10.52702/fce.1224612
[12] Ju, F., Li, J., Xiao, G., Huang, N., & Biller, S. (2014). A flow model s battery manufacturing quality systems for electric vehicles. IEEE Transactions on Automation science and engineering, 11(1), 230-244. https://doi.org/10.1109/TASE.2013.2237765
[13] Kazak, D., & Öncel, H. U. (2024). Firefighters all-electric vehicle fires, with an examination of the struggle. International Journal Of Social Sciences Studies, 10(3), 384-394.
[14] Özcan, F. (2024). Safety recommendations for electric vehicle fires. OHS Turkey. URL: https://www.isgturkiye.com/konu/elektrikli-arac-yanginlari-icin-guvenlik-onerileri.10847/
[15] Shin, Y. (2024). Seesaw - wed, Electric fire fighting equipment. James Dyson Award. RetriURL: https://www.jamesdysonaward.org/2023/project/seesaw-electric-car-fire-fighting-equipment/(access date: 10.01.2025).
[16] Sun, P., Bisschop, R., Niu, H., & Huang, X. (2020). A review of battery fires in electric vehicles. Fire Technology, 56, 1361-1410. https://doi.org/10.1007/s10694-020-00958-2.
[17] Bisschop, R. (2020). Handling the lithium-ion batteries in electric vehicles: recovering from and preventing hazardous events. Fire Technology, 56, 2671-2694. https://doi.org/10.1007/s10694-020-01038-1
[18] Tohir, M., & Martin-Gomez, C. (2023). Electric vehicle fire risk assessment using fault tree analysis framework. Open Research Europe, 1-20. https://doi.org/10.12688/openreseurope.16538.1
[19] Chamber of Mechanical Engineers. (2024). The use of electric vehicles, and fire safety. Ankara: Turkey's electric vehicle working group.
[20] Regulation on the Protection of Buildings from Fire (2007). Republic of Turkey Council of Ministers Decision.
[21] Griffiths, A. (2023). Wed design challenges in fire safety and risk mitigation for electric vehicle parks. URL: https://www.chapmantaylor.com/insights/design-challenges-and-risk-mitigation-for-electric-vehicle-fire-safety (date of access: 10.01.2025).
[22] Colella, F. (2016). Understanding electric vehicle fires. Fire Protection and safety in Tunnels, Stavanger.

[23] Long Jr, R. T., Blum, A. F., Actives, T. J., & Cotts, B. R. T. (2013). Best practices for emergency response incidents involving electric vehicles battery hazards: a preliminary report, the full-scale test results. Journal of chemical information and modeling, 53, 1009-1010.
[24] Hazardous Materials Recognition Guide. (2014). Istanbul: Istanbul Fire Brigade.
[25] Gaziantep Metropolitan Municipality, (2024), Fire Raport "dated 07.05.2024 and numbered 24445"
[26] Flour, C., & Aydin, K. (2021). Thermal runaway and fire suppression applications for different types of lithium-ion batteries. Vehicles, 3(3), 480-497. (Access date: 10.01.2025). https://doi.org/10.3390/vehicles3030029
[27] Said, A. O., & Stoliarov, S. I. (2021). Analysis of the effectiveness of suppression of lithium-ion battery fires with a clean agent. Fire Safety Journal, 121, 103296. https://doi.org/10.1016/j.firesaf.2021.103296
[28] Willstrand, O. (2019). Battery pack for vehicle fire suppression tests. NATIONS Research Institutes of Sweden, Boras, Sweden.
[29] Topal, O. (2023). Turkey in electric and hybrid vehicles for the emergency response approaches. The environment, the climate of the City Journal, 2(3), 190-206.