JOURNAL OF MARITIME RESEARCH

Vol XX. No. III (2023) pp 240–250

ISSN: 1697-4840, www.jmr.unican.es

Transport of Electric and Hybrid Vehicles on Board Ships: Risks and Measures to Consider for a Growing Problem

J.A. González Almeida[1,*], F.H. Hoyos Medina[1], M.C. Adrián de Ganzo[1], A.U. Gómez Correa[1], J. Almenar de Luz[2]

ARTICLE INFO

Article history:
Received 10 Oct 2023;
in revised from 11 Oct 2023;
accepted 21 Nov 2023.

Keywords:
fire prevention, EV, PHEV, fire risk, maritime transport.

ABSTRACT

The transport of electric and hybrid vehicles on passenger ships presents a risk of fire, mainly due to the lithium batteries that power these vehicles. This risk has been evident in several incidents, leading to concern and safety measures by shipping companies. Although there are no specific regulations for the transport of electric vehicles on ships, efforts are being made to develop safe systems for their transport and to adjust international maritime regulations to this new scenario. The International Maritime Organisation has acknowledged the risk of fire on ships carrying electric vehicles and has urged the implementation of safety protocols to reduce this risk. Some shipping lines have banned or restricted the embarkation of these vehicles on their vessels, while others have implemented specific measures, such as the acquisition of fire extinguishing equipment and the training of personnel in extinguishing fires on electric vehicles. In summary, the risk of electric and hybrid vehicle fires on passenger ships is a growing concern that requires the implementation of specific safety measures.

1. Introduction.

Mobility in the 21st century is being transformed by the need to adopt more sustainable forms of transport. In this scenario, electric vehicles (EVs) and hybrids are taking a central role in the automotive industry [1]. These vehicles share key features and technologies that make them promising for a cleaner and more efficient future. With the integration of advanced batteries, innovative propulsion systems and environmental policy support, EVs and hybrids are leading the way towards more sustainable mobility [2].

Electric vehicles (EVs) and hybrids share some similarities, such as the use of electric technology to improve fuel efficiency and reduce emissions. However, they have key differences [3]. EVs run exclusively on electricity, stored in batteries and used to power an electric motor. They have no internal combustion engine and require charging stations. Hybrids, on the other hand, combine an internal combustion engine with an electric motor, allowing them to use both fuel and electricity. Hybrids can be recharged while driving and are not completely dependent on charging stations. These characteristics define their respective benefits and limitations in terms of performance, cost and environmental sustainability. Both types of vehicles rely on advanced rechargeable batteries, usually lithium-ion, to store and supply energy. Although batteries in electric vehicles tend to be larger, those in hybrids also play a crucial role in backing up the internal combustion engine and providing electric assistance under certain conditions [4].

Another point of convergence is the use of regenerative braking. Both types of vehicles incorporate systems that convert the kinetic energy generated during braking and deceleration into electrical energy, thus recharging the batteries. This innovation not only improves efficiency, but also extends the range of the vehicles [5].

Both electric and hybrid vehicles face the common challenge of charging infrastructure. The expansion of fast and accessible charging stations is critical to the success of both, and governments and businesses are working to develop a network

[1]Departamento de Ingeniería Civil, Náutica y Marítima. Universidad de La Laguna.

[2]Fred Olsen Express.

[*]Corresponding author: J.A. González-Almeida. E-mail Address: jagonal@ull.edu.es.

that supports the growing adoption of these vehicles [6].

Safety is a priority in the design of electric and hybrid vehicles. Both types must comply with strict safety regulations and standards, from crash tests to specific protocols for battery thermal management. Training of emergency services also plays a crucial role in ensuring effective responses in case of accidents [7].

2. Background.

2.1. The Growth of Electric and Hybrid Vehicles: A Global Analysis.

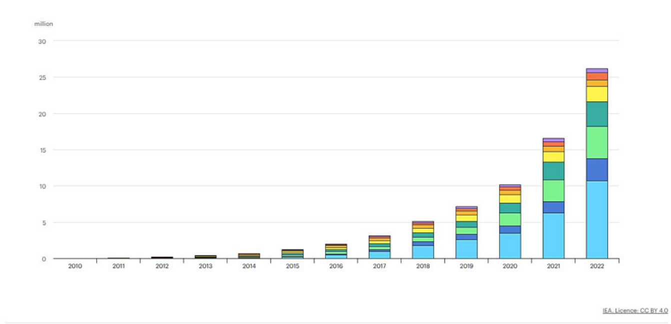
The demand for electric vehicles (EVs) and hybrids worldwide has experienced significant growth in recent years, driven by growing environmental awareness and the implementation of sustainability and environmental protection policies in several countries [8].

2.1.1. Global Market Development.

According to a report by EY, by 2022, the electric vehicle (EV) market will grow by 55%, accounting for 13% of total global vehicle sales, with 10.5 million units sold [9]. This growth has occurred against a backdrop of supply chain disruptions and rising commodity prices, highlighting the robustness of the EV market.

China has emerged as a leader in hybrid electric vehicle production and demand. In October 2022, the wholesale volume of New Energy Vehicle (NEV) passenger cars in China increased by 85.8% year-on-year, with a notable increase in sales of battery electric vehicles (BEVs) and plug-in hybrids (PHEVs) [10].

Figure 1: IEA, Global electric car stock, 2010-2022.



Source: IEA, Paris https://www.iea.org/data-and-statistics/charts/global-electric-car-stock-2010-2022, IEA. Licence: CC BY 4.0.

By the end of 2020, there were 10 million electric cars registered worldwide, with Europe overtaking China as the world's largest EV market, driven in part by proactive government policies [11].

2.1.2. Sustainability Policy and its Impact.

Sustainability policies have played a crucial role in the growth of the EV market. By 2021, global electric car sales will double to a record 6.6 million, driven by continued government policy support and increased public spending on subsidies and incentives [12].

However, the sector faces challenges, including high prices of critical minerals for battery manufacturing and disruptions in the supply chain. In the long term, a concerted effort is required to develop adequate charging infrastructure for electric vehicles [13].

2.1.3. Key Issues in the Growing Demand for Electric Vehicles Worldwide.

Factors such as improved engine performance and fuel efficiency are making EVs more attractive to consumers [14]. In addition, growing environmental awareness and preference for cleaner technologies are driving demand [15]. Another crucial factor is the combination of high fuel prices, lower EV prices, tax incentives and the elimination of charging concerns [16].

The following highlights some of the key aspects that have contributed to the growing demand for electric vehicles worldwide:

- Environmental Awareness: Growing awareness of the environmental impacts of fossil fuel-based transport has led to an increased preference for cleaner, more sustainable vehicles.
- Technological Advances: Continued improvements in battery technology and the expansion of charging infrastructure have increased the attractiveness of electric vehicles, overcoming previous technological barriers.
- Government Incentives: Many governments have implemented tax incentives, subsidies and support policies to encourage the adoption of electric vehicles, making it more attractive to consumers.
- Environmental Regulations: Stricter emissions regulations and pressure to meet climate targets have led automakers to invest in electric vehicles to meet more stringent environmental standards.
- Model Variety: Diversification in electric vehicle model offerings by manufacturers has given consumers more choice, from compact cars to SUVs and luxury vehicles.
- Economy of Scale: As production of electric vehicles has increased, economies of scale have enabled reductions in manufacturing costs, making these vehicles more affordable.
- Consumer Awareness: The shift in consumer perception towards sustainable mobility has been an important driver, with more people recognising the environmental and economic benefits of electric vehicles.

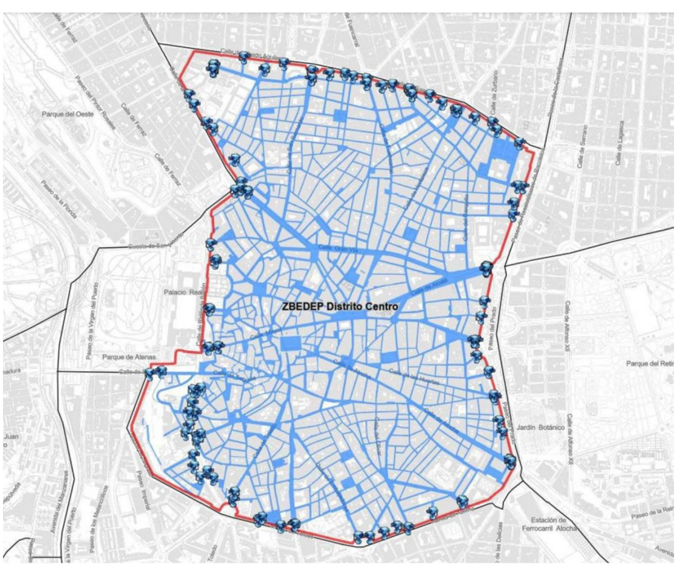
- Corporate Commitments: Many companies, both automotive and non-automotive, have made commitments to sustainability and fleet electrification, contributing to the growing demand for electric vehicles.
- Charging Infrastructure: The expansion of charging infrastructure, including fast chargers and public charging networks, has addressed range concerns and facilitated the adoption of electric vehicles.
- Continued Innovation: Continued innovation in electric vehicle design, performance and features has generated renewed interest and attracted consumers seeking modern driving experiences.

But all this would not be enough if governments did not implement measures to reduce environmental pollution and tacitly prohibit the access of vehicles with combustion engines to city centres. In large cities, this implies the approval of regulations for the implementation of low-emission zones, encouraging the replacement of the current vehicle fleet with non-polluting vehicles.

2.2. Low-emission zones in cities.

Low Emission Zones (LEZs) have emerged as a key response to environmental and air quality challenges in urban settings. These areas, present in cities around the world, are designed to reduce vehicle emissions and promote more sustainable modes of transport [17].

Figure 2: EPZ Madrid.



Source: neomotor.epe.es.

The EPZs are geographical areas within a city where specific restrictions or requirements on emissions produced by vehicles circulating in them are applied. The main objective is to improve air quality by reducing pollution and encouraging the use of cleaner vehicles [18].

The implementation of these low emission zones aims to achieve a number of environmental objectives [19]:

- Improved Air Quality: The reduction of emissions directly contributes to an improvement in air quality, benefiting the health of residents.
- Promotion of Sustainable Transport Modes: EPZs encourage the use of more sustainable modes of transport, such as walking, cycling and public transport.
- Environmental Compliance: They help cities comply with environmental regulations and achieve emission reduction targets.

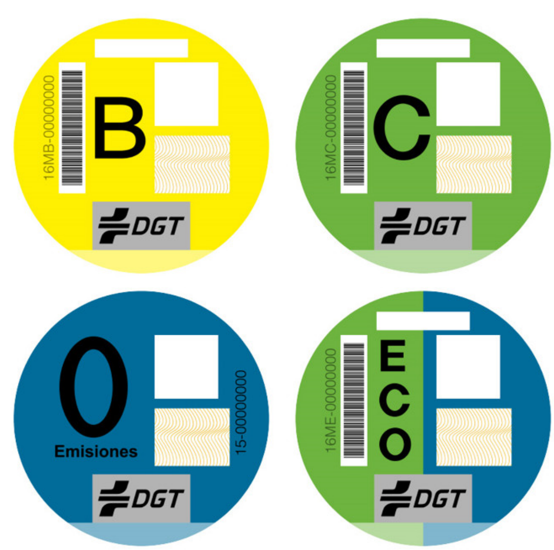
Some key issues about these types of areas within cities are, for example:

- Access Restrictions: EPZs often limit access for vehicles that are highly polluting or do not meet specific emission standards [20].
- Environmental Regulations: These set emission standards that vehicles must meet in order to enter the zone, encouraging the adoption of cleaner technologies [21].
- Incentives for Clean Vehicles: Incentives, such as fee waivers or free parking, are offered to owners of low-emission vehicles [22].

But of course there must be a series of control measures in place to ensure compliance with the rules related to these zones, currently the control of vehicles accessing these zones is mainly based on two formats:

- Vehicle Tagging Systems [23]: Many cities implement vehicle labelling systems that classify vehicles according to their emissions, facilitating identification and compliance.

Figure 3: Environmental vehicle markings in Spain.



Source: industriassaludes.es.

- Access Control Technology: Technologies such as cameras and control systems are used to monitor traffic and ensure compliance with access restrictions.

Figure 4: Barcelona City Hall traffic control room.

Source: LaSexta.es.

In general, both measures are usually implemented at the same time and, more importantly, non-compliance with the measures can lead to a penalty system, which means that the former users of these zones will gradually have to adapt not only to the new regulations but also to change their traditional combustion vehicles for vehicles that comply with the emission reduction regulations, which means a significant investment for them. In the case of Spain, in order to promote compliance with European guidelines for reducing air pollution, in 2019 the MOVES Plan (Plan de Movilidad Eficiente y Sostenible) was approved, a Spanish government initiative designed to promote sustainable mobility. This plan is part of the measures promoted by the government to reduce CO2 emissions and other polluting gases, in line with the European Union's objectives on climate change and energy transition.

The Moves Plan (currently in its third edition), basically consists of the implementation of the following measures [24]:

- Incentives for the Purchase of Electric Vehicles: MOVES Plan offers financial aid for the purchase of electric, plug-in hybrid and fuel cell vehicles. These incentives are aimed at individuals, companies and public entities.

- Charging Infrastructure: This includes aid for the installation of charging points for electric vehicles, both in public spaces and in private homes and companies.

- Electric Bicycle Lending Systems: Promotes sustainable mobility through the promotion of electric bicycle systems, especially in urban areas.

- Sustainable Mobility Measures in Companies: Encourages the implementation of transport plans for employees in companies, seeking to reduce the use of private vehicles and promote more sustainable alternatives.

The MOVES Plan is part of the Spanish government's energy transition policies and is aligned with European Union guidelines on reducing emissions and promoting renewable energies. Although it is a state plan, its management and implementation is decentralised to the autonomous communities, which adapt the plan to their specific needs and particularities.

The MOVES Plan is financed by state funds, often complemented by European funds earmarked for energy transition and the fight against climate change, and each new edition of the MOVES Plan may bring changes in the conditions, requirements and amounts of aid, so it is important to consult the most recent call for proposals for updated information.

2.3. Risk of Fire in Electric (EV) and Hybrid (PHEV) Vehicles.

Transition towards more sustainable vehicles, such as electric and hybrid vehicles, has raised safety concerns, specifically in relation to the risk of fire. Although these vehicles are designed with advanced technologies to minimise risks, it is imperative to explore this aspect in depth and understand the safety measures implemented. In recent years, all major car brands have been including hybrid or pure electric vehicles in their portfolio in response to the demand being experienced.

Factors contributing to the risk of fire include:

- Lithium-ion batteries: Both electric and hybrid vehicles rely on lithium-ion batteries. While energy efficient, these batteries can generate heat, posing a potential fire risk in extreme situations.

- Physical Damage: Severe impacts or significant physical damage can increase the risk of fires, especially in severe traffic accident situations that compromise the integrity of the battery.

- Charging Problems: Charging-related problems, such as overcharging or the use of unauthorised chargers, can contribute to the risk of fire by adversely affecting the thermal management of the battery.

To avoid these risks, manufacturers have implemented a number of safety measures:

- Battery Management Systems: Both types of vehicles are equipped with advanced battery management systems to monitor temperature and prevent hazardous situations.

- Automatic Disconnection: In the event of an accident, many electric vehicles are designed to automatically disconnect battery power, reducing the possibility of fires.

- Stringent Regulations and Standards: Industry and regulatory bodies set strict regulations and standards for the safety of electric and hybrid vehicles, including crash testing and specific protocols for battery safety.

- Technological Innovations: Ongoing research and technological innovations seek to improve battery safety, introducing fire extinguishing systems and safer materials.

- Specialised Training: Emergency services receive specialised training to deal with situations involving electric and hybrid vehicles, ensuring effective and safe responses.

Recent studies have found that the risk of fires in this type of vehicle is no higher than in traditional combustion vehicles [25].

3. Development & Discussion.

3.1. Worldwide transport of vehicles by ship.

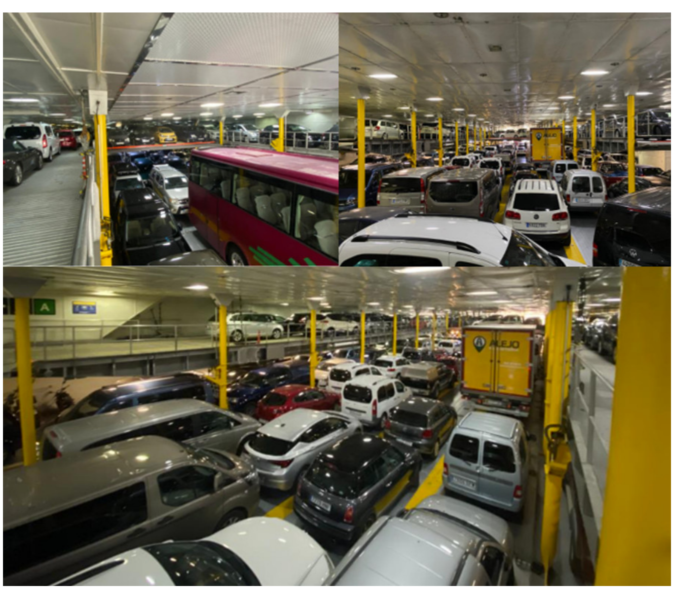
Transporting vehicles by ship worldwide is a complex process that involves various stages, each requiring meticulous planning and coordination [26]. The process can be broadly divided into several key steps:

Preparation and Planning: Before vehicles are transported, there's a need for thorough planning. This includes route planning, considering factors like weather conditions, sea routes, and political situations in different regions. For instance, longer routes might be chosen to avoid areas with piracy risks [27].

Vehicle Logistics and Consolidation: Vehicles are often transported from manufacturing facilities to a consolidation center near the port. Here, they are prepared for shipping, which includes ensuring they are in a drivable condition, disabling alarms, and sometimes partially draining fuel.

Loading onto the Ship: Vehicles are driven onto the ship using their own power. This process is known as "roll-on." The ships used are often specialized Ro-Ro (Roll-on/Roll-off) vessels designed for transporting wheeled cargo. The vehicles are then securely fastened to the deck to prevent movement during transit [28].

Figure 5: Inside Ro-Ro ship in Spain.



Source: Authors.

Maritime Transit: During the sea voyage, the primary concern is the safety and security of the cargo. The ships are equipped with stabilization systems to minimize the effect of rough seas. The route and speed are constantly adjusted to avoid bad weather and ensure timely delivery [29].

Unloading and Distribution: Upon reaching the destination port, the vehicles are driven off the ship, a process known as "roll-off." They are then moved to a holding area where they undergo customs and regulatory checks before being distributed to dealers or end customers.

Regulatory Compliance: International shipping of vehicles involves compliance with various regulations. This includes customs laws, environmental regulations (like the International Maritime Organization's regulations on emissions), and safety standards [30].

Insurance and Risk Management: Transporting vehicles by sea carries risks like damage due to weather, accidents, or piracy. Therefore, insurance is a critical aspect, covering potential damages or losses during transit [31].

Technological Integration: The use of technology in tracking and managing the logistics is vital. GPS tracking, RFID tags, and other technologies enable real-time tracking of the vehicles throughout the journey [32].

Environmental Considerations: The shipping industry is increasingly focusing on reducing its environmental impact. This includes using ships with lower emissions, optimizing routes for fuel efficiency, and exploring alternative fuels [33].

3.2. Transport of vehicles on board ships in Spain.

Transporting vehicles by ship in Spain is a specialized segment of the maritime logistics industry, reflecting the country's position as both a significant automotive manufacturer and a hub in Mediterranean and Atlantic shipping routes [34]. Here's a detailed overview:

- Key Ports and Infrastructure: Spain's main ports for vehicle shipping are Barcelona, Valencia, and Bilbao. These ports have specialized infrastructure, including large Ro-Ro (Roll-on/Roll-off) terminals, to facilitate the efficient loading and unloading of vehicles [35].

- Automotive Industry Integration: Spain is home to several major automobile manufacturing plants, including those of SEAT, Volkswagen, and Ford. The proximity of these plants to ports like Barcelona and Valencia facilitates efficient transport logistics. Vehicles are often transported from the factory to the port via short road trips or rail [36].

- Loading and Shipping Procedures: The Ro-Ro method is predominantly used for loading vehicles onto ships. This process involves driving vehicles directly onto the ship, where they are securely fastened. Spanish ports are equipped with advanced systems to handle a high volume of vehicles efficiently [37].

- Regulatory Framework: Spain, being part of the European Union, adheres to EU regulations regarding maritime transport. This includes environmental regulations, safety standards, and customs procedures. Spanish ports are often audited for compliance with international shipping standards [38].

- Shipping Routes: Spain's geographical location offers strategic advantages for vehicle shipping. The ports serve as gateways to Africa, the Middle East, and Latin America, in addition to connecting with other European ports. This makes Spain a critical node in the global automotive shipping network [39].

- Technological Advancements: Spanish ports utilize advanced technology for logistics management, including digital tracking systems, automated scheduling, and RFID tagging for real-time tracking of vehicles [40].
- Environmental Considerations: Spanish ports and shipping companies are increasingly adopting eco-friendly practices, such as using ships with lower sulfur emissions and exploring alternative fuels like LNG (Liquefied Natural Gas) [41].
- Challenges and Opportunities: The Spanish vehicle shipping sector faces challenges like fluctuating global trade patterns and economic fluctuations. However, there are opportunities in expanding capacity and enhancing technological integration [42].

3.3. The transport of electric and hybrid vehicles on board ships.

3.3.1. On-board fires caused by electric and hybrid vehicles.

Fires on board ships caused by electric vehicles (EVs) and hybrids are an area of growing concern in the maritime industry [43]. Although fires in EVs are no more common or intense than fires in internal combustion engine vehicles (ICEVs), lithium-ion batteries in EVs present unique challenges, especially in the context of a maritime environment [44].

First, we will discuss here the accident of the Felicity Ace (IMO 9293911) a representative case that highlights the risks associated with the maritime transport of EVs. On 16 February 2022, the Felicity Ace, a vehicle cargo ship built in 2005, suffered a fire while transiting the Atlantic [45]. On board were approximately 4,000 vehicles, including models from luxury brands such as Porsche, Audi, Bentley and Lamborghini, along with lithium-ion batteries.

Figure 6: Felicity Ace on fire.

Source: Marinha PT.

The ship's crew was safely evacuated, and no injuries were reported among the 22 crew members. However, the fire persisted for two weeks, making extinguishing operations difficult due to the nature and location of the fire on the vessel. Efforts to tow the vessel began on 24 February, but on 1 March 2022, during the towing process, the Felicity Ace lost stability and eventually sank some 25 nautical miles outside Portugal's exclusive economic zone, at a depth of approximately 3000 metres [46].

The estimated value of the vehicles on board was estimated at around $401 million [47]. Although the lithium batteries in the electric vehicles on board were identified as a factor that could have contributed to the intensity of the fire, the exact cause of the fire has not been definitively determined, but it is believed that the lithium batteries in some of the electric vehicles being transported made it very difficult to control and extinguish the fire, which ultimately led to the abandonment of the vessel and its subsequent sinking. The ship was carrying more than 100 purely electric vehicles, of the Audi E-Tron model [48]. In fact, some media reported that a few years earlier in 2019, owners of this vehicle model were invited by the brand to attend the dealership to check the wiring as the brand had reported that its batteries were at risk of catching fire due to a design error [49]. Anecdotally, there was a collision between an Audi E-Tron in Canada and another vehicle at a traffic light, where the Audi's battery became detached from the vehicle due to the collision and subsequently caught fire [50]. The industry of vehicles with lithium-ion batteries is growing rapidly due to high demand, so it is not uncommon that, as with almost any product that is put on the market, manufacturing errors are detected afterwards which, although they are rectified over time, cause major problems for users, for example in the automotive sector there are currently many users who report problems due to failures in the MCI 1. 2 l three-cylinder Puretech 110 or 130 hp engines from the defunct PSA group manufactured between 2013 and 2017, with more than 200,000 vehicles affected [50]. As we can see, these are not isolated to EVs, but they are issues that need to be considered because of the risks involved.

Figure 7: Battery pack of an Audi e-tron is seen being ejected from the EV and onfire.

Source: electrck.co.

The sinking of the Felicity Ace highlighted the unique challenges presented by electric vehicle shipping, including the management of fire risks associated with lithium-ion batteries [52].

Research by EU Project LASHFIRE, with IUMI participation, indicates that neither the rate of fire growth nor the maximum heat release rate or total energy released during a fire is higher in an EV fire than in an ICEV fire [53]. However, it is highlighted that exposure of lithium-ion batteries to fire can result in thermal runaway, which requires a different approach to fire detection and response.

In addition, the challenge of extinguishing battery fires on ships is complex due to limited space conditions, making it difficult for firefighters to access and use traditional firefighting tactics. Shipping companies are implementing measures such as specifying a minimum and maximum state of charge for EV batteries and developing specialised methods for battery fire suppression [54] [55].

Just over a year later, another such incident occurred again on board a vessel carrying both conventional and electric vehicles. The fire on the Fremantle Highway was a significant incident that again raised concerns about the safety of electric vehicle (EV) shipping. The fire occurred on 25 July while the vessel was en route from Germany to Egypt, off the coast of the Netherlands. The Fremantle Highway was carrying nearly 4,000 cars, including approximately 500 EVs. One crew member lost his life and others were injured, some having to jump overboard to escape the flames [56].

Figure 8: Fremantle Highway on July 28th.

Source: Kustwacht Nederland.

Figure 9: Inside Fremantle Highway.

Source: RTL.

Initially, it was speculated that an EV might have been the cause of the fire. However, subsequent investigations suggested that the fire might not be related to the EVs and could have been caused by an internal combustion vehicle (ICE) or some other cause [57]. Reports indicate that the four lower decks of the vessel, where the EVs were located, were largely intact, while the four upper decks were severely damaged, with vehicles completely charred in place. Despite initial speculation, the cause of the fire has not yet been officially determined. The International Maritime Organisation (IMO) and the International Union of Marine Insurance (IUMI) are investigating the fire risks associated with EVs on ships [58].

The incident has highlighted the need for greater understanding and management of the risks associated with transporting electric vehicles on ships, including the possibility of fires and the difficulty of fighting them at sea.

3.3.2. Cause of this fires aboard.

The main causes of fires in electric and hybrid vehicles on passenger ships include lithium-ion battery problems, short circuits, overheating and damage to the battery management system. The transport of electric cars on ships has been linked to fires due to the possibility of lithium-ion batteries emitting smoke containing hydrogen fluoride, an extremely harmful substance.

Fires involving lithium-ion batteries have long been a challenge for both fire-fighting services and preventive measures, for several reasons, but mainly because they are not very predictable: while some batteries may burn during charging, others, for example, may burn due to contact with salt water, and others simply due to design flaws [59]. On the other hand, ship garages tend to organise vehicles in such a way as to make the best use of space, so that sometimes it is very difficult even for people to pass between two parked vehicles and in the event of an emergency, extinguishing can be delayed due to difficulties in accessing the vehicle and, on the other hand, the spread of the fire is very rapid because it quickly affects the other vehicles around it, just a few tens of centimetres away. And finally, the very chemical nature of the battery itself, with multiple specific chemical components, also makes it very difficult to extinguish.

Figure 10: Electric car on fire on a ferry from Oslo to Copenhagen in 2010, photo by MsCandy.

Source: International Fire Protection Magazine.

It has been demonstrated with real evidence that fires from electric vehicles can pose a risk in maritime transport, leading to the adoption of specific safety measures on some ships. These causes have raised concerns in the maritime industry and have prompted the implementation of safety protocols to mitigate the risk of fires on ships carrying electric and hybrid vehicles [60].

3.3.3. Safety measures to prevent fires on electric and hybrid vehicles on passenger ships.

In many different countries, a number of safety measures are being implemented to prevent fires from electric and hybrid vehicles on passenger ships. Some of these measures include [61]:

- Strict safety protocols: Some shipping lines have implemented stringent safety protocols for the boarding and transport of electric vehicles, including taking the temperature of vehicles on board with a heat gun and placing fire blankets in case of fire.
- Training of personnel in electric vehicle firefighting: Some shipping lines are training their personnel in electric vehicle firefighting, and have incorporated fire detection and extinguishing equipment on their vessels specifically for electric vehicles.
- Development of monitoring tools and technologies: Tools are being developed to monitor the temperature of vehicles, such as ground-based drones and sensor arcs to detect hot spots in vehicles, in order to prevent fires.

These measures seek to mitigate the risk of fires on ships carrying electric and hybrid vehicles, and reflect the growing concern for safety in the maritime transport of this type of vehicle. At the European level, we can highlight the LASH FIRE initiative [62], a project promoted by the European Commission following several EMSA studies on maritime fires on Ro-Ro and Ro-Pax vessels, where thirty serious fires on this type of vessel have been reported in barely a decade. Despite this, the fear of these fires in electric and hybrid vehicles is still very topical, to the point where some shipping companies have refused to embark electric vehicles despite having the required ticket and arguing the growing concern in the sector about the risk of fire in these vehicles [63].

Conclusions

Fires in electric and hybrid cars on ships are a topic of growing interest and concern in the maritime industry. Several important conclusions can be drawn from reported incidents and research:

- Increased Potential Risk: Electric and hybrid vehicles, due to their lithium-ion batteries, present a potentially increased risk of fire compared to internal combustion vehicles. This is due to the possibility of batteries undergoing what is known as ”thermal runaway”, a process where excessive heat can cause a fire.
- Fire Fighting Challenges: Fires involving lithium-ion batteries are particularly difficult to extinguish. They may require large amounts of water or special extinguishing agents, and there is a risk of rekindling the fire due to the nature of the batteries.
- Need for Specific Protocols: The safe management of electric and hybrid vehicles on board ships requires specific protocols, both in terms of storage and handling and emergency response. This includes proper segregation of these vehicles from other types of cargo and specialised training for ship's crew.
- Evolving Research and Regulations: Organisations such as the International Maritime Organisation (IMO) are actively investigating the risks associated with the carriage of electric and hybrid vehicles. This could lead to the implementation of new regulations and safety standards in the future.
- Importance of Manufacturer Cooperation: Manufacturers of electric and hybrid vehicles play a crucial role in this scenario, as their collaboration is essential to better understand the risks and develop effective prevention and response strategies.
- Environmental and Safety Impact: Although electric and hybrid vehicles are promoted for their lower environmental impact, safety risks, especially in maritime transport, must be carefully assessed and managed to ensure a balance between sustainability and safety.

In conclusion, the transport of electric and hybrid vehicles on ships represents an emerging safety challenge. A proactive approach is needed, including continuous research, development of specific safety protocols, collaboration between stakeholders and adaptation to new technologies and associated risks.

References.

[1] F. M. Moreno, «Vehículos Eléctricos. Historia, Estado Actual Y Retos Futuros,» European Scientific Journal, ESI, vol. May, pp. 118-131, 2016.

[2] M. M. d. Miguel, «Análisis sobre las plataformas de coches eléctricos.,» Universidad Politécnica de Valencia, Valencia, 2021.

[3] Ihobe S.A., «Comparativa ambiental entre diferentes alternativas de vehículos: Eléctrico, híbrido y combustión,» Ihobe Sociedad Pública de Gestión Ambiental. Departamento de Medio Ambiente, Planificación Territorial y Vivienda. Gobierno Vasco., Bilbao, 2020.

[4] I. Husain, Electric and Hybrid Vehicles: Design Fundamentals, Boca Raton: CRC Press, 2021.

[5] C. C. M. e. al., «Comparative Study of a Regenerative Braking System and Regeneration with Constant Kinetic Energy in Battery-based Electric Vehicles,» Ingeniería, vol. 25, nº 3, pp. 305-322, 2020.

[6] J. M. H. y. N. I. González, «Las infraestructuras de recarga y el despegue del vehículo eléctrico,» Observatorio Medioambiental , vol. 18, pp. 54-85, 2015.

[7] DAFO BRAND AKTIEBOLAG, «An Automated HEV and EV Vehicle Fire Early Warning and Suppression System. Li-IonFire.,» H2020-SMEInst-2014-2015, Sweden, 2015.

[8] VVAA, «La Movilidad Sostenible del futuro y el impacto sobre los ODS,» III Observatorio de la Movilidad Sostenible. Mobility City, F. Ibercaja & Grant Thornton. , Zaragoza, 2022.

[9] Ernst & Young Global Limited (EYG), «El mercado del vehículo eléctrico aumenta un 55% a nivel mundial,» Ernst & Young Global Limited (EYG), 18 mayo 2023. [En línea]. Available: https://www.ey.com/es_es/news/2023/05/el-mercado-vehiculo-electrico-aumenta-55-nivel-mundial#:~:text=La%20venta%20del%20veh%C3%ADculo%20de,despliegue%20definitivo%20del%20veh%C3%ADculo%20el%C3%A9ctrico. [Último acceso: 26 octubre 2023].

[10] Mordor Intelligence Private Limited, «Análisis del tamaño y la participación del mercado de automóviles híbridos tendencias de crecimiento y pronósticos (2023 - 2028),» Mordor Intelligence Industry Reports, Telangana - India, 2023.

[11] IEA, «Global electric car stock, 2010-2022,» International Agency Energy, 5 abril 2023. [En línea]. Available: https://www.iea.org/data-and-statistics/charts/global-electric-car-stock-2010-2022. [Último acceso: 12 octubre 2023].

[12] IEA, «Informe Global EV Outlook 2021 sobre movilidad eléctrica,» International Energy Agency, abril 2021. [En línea]. Available: https://esmovilidad.mitma.es/noticias/informe-global-ev-outlook-2021-sobre-movilidad-electrica. [Último acceso: 03 octubre 2023].

[13] IEA, «Informe Global EV Outlook 2022 sobre vehículo eléctrico,» Agencia Internacional de la Energía, Mayo 2022. [En línea]. Available: https://esmovilidad.mitma.es/noticias/informe-global-ev-outlook-2022-sobre-vehiculo-electrico. [Último acceso: 12 octubre 2023].

[14] S. S. D. K. N. e. a. Afandizadeh, «Using machine learning methods to predict electric vehicles penetration in the automotive market,» Scientific Reports, vol. 13, nº 8345, 2023.

[15] J. B. B. e. al., Energy prices and electric vehicle adoption, Cambridge: National Bureau of Economic Research, March, 2022.

[16] K. e. al., «Google Trends and vehicle sales: A correlation study.,» Scientific Reports, 2023. W567W8504[17] ITDP, «What Is A Low Emission Zone?,» Institute for Transportation & Development Policy, New York, 2023.

[18] MITECO, «Directrices para la creación de zonas de bajas emisiones (ZBE),» Ministerio para la Transición Ecológica y el Reto Demográfico, Madrid, 2021.

[19] J. M. V. M. e. al., Impacto en la aceptabilidad y reparto modal de las medidas para mejorar la calidad del aire en Madrid Central, Burgos.: Universidad de Burgos. Servicio de Publicaciones e Imagen Institucional, 2021.

[20] A. Otero, «Estas son las ZBE ya activas y así restringen a los coches con etiqueta B y C de la DGT,» Motor Pasión, 25 septiembre 2023. [En línea]. Available: https://www.motorpasion.com/futuro-movimiento/estas-zbe-activas-asi-restringen-a-coches-etiqueta-b-c-dgt. [Último acceso: 10 octubre 2023].

[21] BOE, «Real Decreto 1052/2022, de 27 de diciembre, por el que se regulan las zonas de bajas emisiones.,» Ministerio de la Presidencia, Relaciones con las Cortes y Memoria Democrática. Agencia Boletín Oficial del Estado, Madrid, 2022.

[22] IDAE, «Guía para la promoción del vehículo electrico en las ciudades,» Instituto para la Diversificación y Ahorro de Energía, Madrid, 2011.

[23] BOE, «Orden PCI/810/2018, de 27 de julio, por la que se modifican los anexos II, XI y XVIII del Reglamento General de Vehículos, aprobado por Real Decreto 2822/1998, de 23 de diciembre.,» Boletín Oficial del Estado. Ministerio de la Presidencia, Relaciones con las Cortes e Igualdad, Madrid, 2018.

[24] IDAE, «PLAN MOVES. INCENTIVOS A LA MOVILIDAD EFICIENTE Y SOSTENIBLE,» Instituto para la Diversificación y Ahorro de la Energía., 26 febrero 2019. [En línea]. Available: https://www.idae.es/ayudas-y-financiacion/para-movilidad-y-vehiculos/convocatorias-cerradas/plan-moves-incentivos-la. [Último acceso: 11 octubre 2023].

[25] G. Ficarazzi, «Recursos y retos de la extinción de incendios en coches eléctricos,» Cuadernos de Seguridad, 14 junio 2023. [En línea]. Available: https://cuadernosdeseguridad.com/2023/06/incendios-en-coches-electricos/. [Último acceso: 09 octubre 2023].

[26] UNCTAD, «Review of Marítime Transport,» United Nations Publications , New York, 2022.

[27] BIMCO et al., «Global Counter Piracy Guidance for Companies, Masters and Seafarers,» Witherby Publishing Group Ltd , Scotland, UK, 2018.

[28] Cross Country Car Shipping, «How Are Cars Loaded Onto Ships? (Detailed guide),» 8 junio 2023. [En línea]. Available: https://vernonnector.medium.com/how-are-cars-loaded-onto-ships-detailed-guide-ea4b8d035867. [Último acceso: 8 octubre 2023].

[29] EMSA, «European Maritime Safety Report 2022,» European Maritime Safety Agency, Luxembourg, 2022.

[30] A. Fedorenkova, «EU's Role in International Environmental Politics, does it help?: Interplay between IMO and EU Oil Pollution Regimes,» Environmental Policy Group. Wageningen University , Paises Bajos, 2007.

[31] J. Tan, «What Is Marine Cargo Insurance, And Why Is It Important?,» MGS Offshore, 15 febrero 2023. [En línea]. Available: https://mgsicestorm.com/marine-cargo-insurance/. - [Último acceso: 06 octubre 2023].

[32] M. S. S. Weng Chun Tan, «Review of RFID and IoT integration in supply chain management,» Operations Research Perspectives, vol. 9, nº 100229, 2022.

[33] H. K. Z. H. M. Veronica Jaramillo Jimenez, «A review of ship energy efficiency research and directions towards emission reduction in the maritime industry,» Journal of Cleaner Production, vol. 366, nº 132888, 2022.

[34] O. A. L.-D. C. P. M. G. F. A. Ortega, «Maritime Transport as a Key Element in the Automotive,» - JMR - Journal of Maritime Research, vol. X, nº 3, pp. 79-82, 2013.

[35] A. M. e. al., «Seaport capacity manual: Application to container terminals,» Fundación VALENCIAPORT, Valencia, 2012.

[36] S. D. Judit Montoriol Garriga, «Spain's automotive industry: strategic and undergoing a transformation,» Caixabank Research, 14 julio 2021. [En línea]. Available: https://www.caixabankresearch.com/en/sector-analysis/industry/spains-automotive-industry-strategic-and-undergoing-transformation. [Último acceso: 03 octubre 2023].

[37] A. G. Camps, «Car carrier operational guide and proposal for an optimization system,» Universitat Politècnica de Catalunya , Barcelona, 2020.

[38] European Parliament, «Maritime transport: Traffic and safety rules,» European Parliament, abril 2023. [En línea]. Available: https://www.europarl.europa.eu/factsheets/en/sheet/125/-maritime-transport-traffic-and-safety-rules. [Último acceso: 03 octubre 2023].

[39] R. K. Arnaud Serry, «Spanish container ports integration in the maritime network,» JMR - Journal of Maritime Research, vol. 17, nº 3, pp. 10-17, 2020.

[40] G. &. B. B. &. B. E. Casella, «The evolution of RFID technology in the logistics field: a review.,» Procedia Computer Science., nº 200, pp. 1582-1592, 2022.

[41] G. F. Patrizia Serra, «Towards the IMO's GHG Goals: A Critical Overview of the Perspectives and Challenges of the Main Options for Decarbonizing International Shipping,» Sustainability , vol. 12, nº 8, p. 3220, 2020.

[42] F. Alanazi, «Electric Vehicles: Benefits, Challenges, and Potential Solutions for Widespread Adaptation,» Applied Sciences, vol. 13, nº 10, p. 6016, 2023.

[43] Todotransporte.com, «Las baterías de los vehículos eléctricos preocupan a los trasportistas marítimos,» Todotransporte-.com, 1 diciembre 2022. [En línea]. Available: https://www.todotransporte.com/texto-diario/mostrar/4094377/baterias-vehiculos-electricos-preocupan-trasportistas-maritimos. [Último acceso: 03 octubre 2023].

[44] C. M.-G. Mohd Zahirasri Mohd Tohir, «Electric vehicle fire risk assessment framework using Fault Tree Analysis,» Open Res Europe, nº 3, p. 178, 2023.

[45] S. Sharma, «Fire-wrecked cargo ship carrying thousands of luxury cars sinks after floating in Atlantic for weeks,» Independent.co.uk, 02 marzo 2022. [En línea]. Available: https://-www.independent.co.uk/news/world/americas/ship-fire-luxury-car-sink-atlantic-b2026499.html. [Último acceso: 04 octubre 2023].

[46] E. Haun, «Burnt Car Carrier Felicity Ace Sinks,» MarineLink, 1 marzo 2022. [En línea]. Available: https://www.marinelink.com/news/burnt-car-carrier-felicity-ace-sinks-494679. -[Último acceso: 02 octubre 2023].

[47] P. Holderith, «It's Been Exactly One Year Since the Felicity Ace Caught Fire With Nearly 4,000 Cars Onboard,» The Drive, 16 febrero 2023. [En línea]. Available: https://www.thedrive.com/news/its-been-exactly-one-year-since-the-felicity-ace-caught-fire-with-nearly-4000-cars-onboard. [Último acceso: 02 octubre 2023].

[48] M. Trueno, «Here's a list of cars that sank with the Felicity Ace car carrier,» CarExpert: Research, buy & sell with confidence, 03 abril 2022. [En línea]. Available: https://www.-carexpert.com.au/car-news/heres-a-list-of-cars-that-sank-with--the-felicity-ace-car-carrier. [Último acceso: 04 octubre 2023].

[49] D. Gutiérrez, «El Audi e-tron es llamado a revisión por un potencial riesgo de incendio,» LaSexta.com, 15 julio 2019. [En línea]. Available: https://www.lasexta.com/motor/noticias/-audi-etron-llamado-revision-potencial-riesgo-incendio_201906-115d0010f70cf21df7ccbe0e75.html. [Último acceso: 04 octubre 2023].

[50] F. Lambert, «Audi e-tron battery pack is seen ejecting during a crash,» Electrek, 02 febrero 2023. [En línea]. Available: https://electrek.co/2023/02/02/audi-e-tron-battery-pack--seen-ejecting-during-crash/. [Último acceso: 05 octubre 2023].

[51] Y. Lethuillier, «¿Hay problemas con el motor 1.2 PureTech del extinto Grupo PSA?,» Motor1.com, 20 abril 2023. [En línea]. Available: https://es.motor1.com/news/466419/motor-puretech-psa-llamada-revision/. [Último acceso: 01 octubre 2023].

[52] Rife Insights: Marine News. , «Everything about Felicity Ace Fire,» Rife Insights: Marine News. , 17 febrero 2022. [En línea]. Available: https://www.rifeconsultancy.com/news/-felicity-ace-fire/. [Último acceso: 06 octubre 2023].

[53] M. Schuler, «Burning Questions: Unraveling the Truth Behind Electric Vehicle Fires in Maritime Shipping,» gCaptain, 11 agosto 2023. [En línea]. Available: https://gcaptain.com/burning-questions-unraveling-the-truth-behind-electric-vehicle-fires-in-maritime-shipping/. [Último acceso: 02 octubre 2023].

[54] A. D. Lisa Baertlein, «Focus: Ocean shippers playing catch up to electric vehicle fire risk,» Reuters, 28 julio 2023. [En línea]. Available: https://www.reuters.com/business/autos-transportation/ocean-shippers-playing-catch-up-electric-vehicle-fire-risk-2023-07-27/. [Último acceso: 03 octubre 2023].

[55] E. Sutcliffe, «Electric vehicle fires on ships & ferries,» -EVFireSafe.com, 23 febrero 2022. [En línea]. Available: https:-//www.evfiresafe.com/post/electric-vehicle-fires-on-ships-ferries. [Último acceso: 04 octubre 2023].

[56] J. Gómez, «Las pérdidas por el incendio del buque Fremantle Highway superan los 274 millones de euros,» Diario de Transporte, 03 agosto 2023. [En línea]. Available: https://www.diariodetransporte.com/articulo/transporte-maritimo-y-puertos/perdidas-incendio-buque-fremantle-highway-superan-274-millones-euros/20230803145129085712.html. [Último acceso: 02 octubre 2023].

[57] J. Costas, «Continúa el misterio del incendio del Fremantle Highway,» Motor.es, 16 agosto 2023. [En línea]. Available: https://www.motor.es/noticias/kia-ev5-2024-fotos-espia--202396811.html. [Último acceso: 02 octubre 2023].

[58] J. M. R. Leal, «Las consecuencias del incendio del Fremantle Highway empiezan a salir a la luz,» Soymotor.com, 08 agosto 2023. [En línea]. Available: https://soymotor.com/coches-/noticias/las-consecuencias-del-incendio-del-fremantle-highway-empiezan-salir-la-luz. [Último acceso: 04 octubre 2023].

[59] L. Vicente, «¿Sueñan los cruceros con coches eléctricos?,»-Cottes Group, 02 febrero 2023. [En línea]. Available: https://www-.cottesgroup.com/blog/suenan-los-cruceros-con-coches-electricos. [Último acceso: 03 octubre 2023].

[60] J. J. C. Vega, «El riesgo latente: Incendios en transportes marítimos de vehículos eléctricos,» SigmaXpert Sure, 04 agosto 2023. [En línea]. Available: https://www.linkedin.com/-pulse/el-riesgo-latente-incendios-en-transportes-mar%C3%AD-

timos-de-c%C3%B3rdoba-vega/?originalSubdomain=es. [Último acceso: 03 octubre 2023].

[61] PiexNext, «Innovación en seguridad: el riesgo de incendios en los buques del futuro,» PiexNext - Innovation by Port de Barcelona., 28 octubre 2022. [En línea]. Available: https://piernext.portdebarcelona.cat/movilidad/innovacion-en-seguridad-el-riesgo-de-incendios-en-los-buques-del-futuro/. [Último acceso: 04 octubre 2023].

[62] Redacción Naucher, «Proyecto Lash Fire: la búsqueda de la seguridad para los buques Ro-Ro,» Naucher Global, 16 enero 2020. [En línea]. Available: https://www.naucher.com/proyecto-lash-fire-la-busqueda-de-la-seguridad-para-los-buques-ro-ro/. [Último acceso: 02 octubre 2023].

[63] CTIF, «Una naviera noruega prohíbe los coches eléctricos a bordo de un ferry clásico,» CTIF - International Association of Fire and Rescue Services, 07 febrero 2023. [En línea]. Available: https://www.ctif.org/es/news/una-naviera-noruega-prohibe-los-coches-electricos-bordo-de-un-ferry-clasico. [Último acceso: 01 octubre 2023].