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Fire Incidents, Trends, and Risk Mitigation Framework of Electrical Vehicle Cars in Australia

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Abstract: Electric Vehicles (EVs) offer a promising solution to reduce the environmental impact compared to internal combustion engine vehicles. However, EV adoption in Australia has been hindered by concerns over fire safety. This study aims to comprehensively analyse EV fire risks and trends in Australia, including those related to charging stations and lithium-ion batteries. The research utilises secondary data from various reputable sources to develop statistical forecasting models, which estimate that Australia will have approximately 1.73 million EVs by 2030 and 15.8 million by 2050. The study reveals an average EV fire frequency of six fires per million EVs in Australia, aligning with the global average. Consequently, Australia is expected to experience 9 to 10 EV fire incidents annually in 2030, 37 to 42 EV fire incidents annually in 2040, and 84 to 95 EV fire incidents annually in 2050. To address these risks, an EV fire risk control framework is considered to identify and recommend appropriate measures for life safety, lithium-ion batteries, charging, EV handling, and EV locations. This research provides vital evidence for regulators, policymakers, and the fire industry to effectively manage EV fire risks and enhance preparedness for the growing EV market in Australia.

Keywords: electrical vehicles; electric vehicles in Australia; EV fires; fire incidents; EV fire statistics

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1. Introduction

Electric vehicles (EVs) have gained significant attention as a promising solution for reducing carbon emissions and improving energy efficiency [1,2]. Analysts predict that in the coming decades, EV will play a crucial role in reducing the emission of CO_2 in the automobile industry [3]. However, fire safety concerns have slowed their adoption in Australia [4]. An analysis of Australian carpark fire statistics revealed that the country experiences an average fire frequency of 2130 fires per million vehicles [5]. However, given the low penetration of EVs (less than 0.1% as of 2020) and no recorded EV fires, further analysis specific to EVs was not justified. Based on existing data, the average EV fire frequency in Australia is six fires per million EVs, significantly lower than the frequency for all vehicles. Similarly, in the United States, EVs account for less than 0.03% of annual car fires, with an estimated 55 fires per year, compared to 284,130 fires in internal combustion engine vehicles. Additionally, studies have shown that battery electric vehicles (BEVs) have a lower fire rate in fatal collisions compared to gasoline vehicles, attributing this to the less combustible nature of lithium-ion batteries, the reduced complexity of EVs, and the location of the fuel source away from the front of the vehicle [5].

The higher incidence of fires in internal combustion engine vehicles (ICEVs), compared to EVs can be attributed to several factors. Firstly, the highly flammable nature of gasoline and diesel fuels used in ICEVs makes them more susceptible to igniting during collisions or incidents. In contrast, EVs utilise lithium-ion batteries, which are less combustible [6]. Secondly, the complexity and number of moving parts in ICEVs increase the likelihood of malfunctions or failures that can lead to fires. EVs have simpler designs and fewer moving parts, reducing the probability of mechanical failures. Lastly, the location of the fuel source plays a role, as the fuel in ICEVs is located within the vehicle and more vulnerable to damage, while the batteries in EVs are often situated beneath the passenger compartment, minimising the risk of damage in frontal collisions [6].

Despite the growing interest in EVs and the Australian Government's focus on climate change policies and incentives for EV adoption, there needs to be more comprehensive research on EV fire risks in the country. Existing studies on fire risks and protection measures have limitations, such as a scarcity of full-scale fire tests for EVs and a small number of reported EV fire incidents in Australia. Additionally, gaps exist in the knowledge of risks, consequences, and mitigation measures, including future statistics on EV numbers. Therefore, it is crucial to address these gaps through research to support the safe integration of EVs into the Australian market. This study aims to provide an in-depth understanding of EV fire risks and mitigation measures, estimate EV uptake, and enhance preparedness to respond to fire safety incidents. The outcomes of this research will benefit Australian regulators, policymakers, and the fire industry, including the fire brigade.

2. Research Methodology

This study employed a systematic literature review methodology to ensure an organised, transparent, and reproducible approach for synthesising research findings and collecting and analysing data. The systematic literature review methodology adopted for this study is illustrated in Figure 1, providing an overview of the systematic approach followed in collecting and analysing the literature. The systematic review process that was chosen relied on secondary data sources, including conference papers, journal articles, books, and scientific reports. A comprehensive search was conducted using various scientific databases such as Google Scholar, ScienceDirect, Elsevier, and Scopus, as well as specific sources like FRNSW, ABCB, government websites, International Energy Agency (IEA), and Australian Bureau of Statistics (ABS). The search focused on specific keywords related to battery fire, EV fire, and EV risks. The initial search resulted in many articles and websites (112 resources). These resources were then screened based on their relevance to the research aim, resulting in a refined set of resources (81 resources). Exclusions were made for topics outside the research scope, such as EV risks not associated with fire and information from unreliable sources.

2.1. Data Collections

The baseline of data collection was obtained from researching scientific articles published on Google Scholar, ScienceDirect, and other databases such as FRNSW, ABCB, IEA, EVC, ABS, EV FireSafe, Bloomberg, McKinsey, Commonwealth Scientific and Industrial Research Organisation (CSIRO), Clean Energy Finance Corporation (CEFC) and Government reports such as National Electric Vehicle Strategy 2023 by the Department of Climate Change, Energy, the Environment and Water, the Future Fuels Strategy by DISER, and Australia's Emissions Projections 2022. The search focused on specific keywords such as EV numbers, ICEV numbers, Australian motor vehicles, ten-year car statistics, passenger vehicles, EV projections globally, EV projections for Australia, forecasting models, EV projected targets for Australia, EV projected targets globally, global car market, EV growth rate, cars growth rate, Compound Annual Growth Rate (CAGR), and EV strategies for Australia. These keywords were chosen to screen data sources and articles based on the critical criteria and relevance to the main aim and objectives, including research questions related to EV uptake in Australia. This analysis was used to inform the section on forecasted EV fire incidents for Australia. The methodology for predicting EV numbers for Australia is summarised in the steps 2 and 3 of Figure 1.

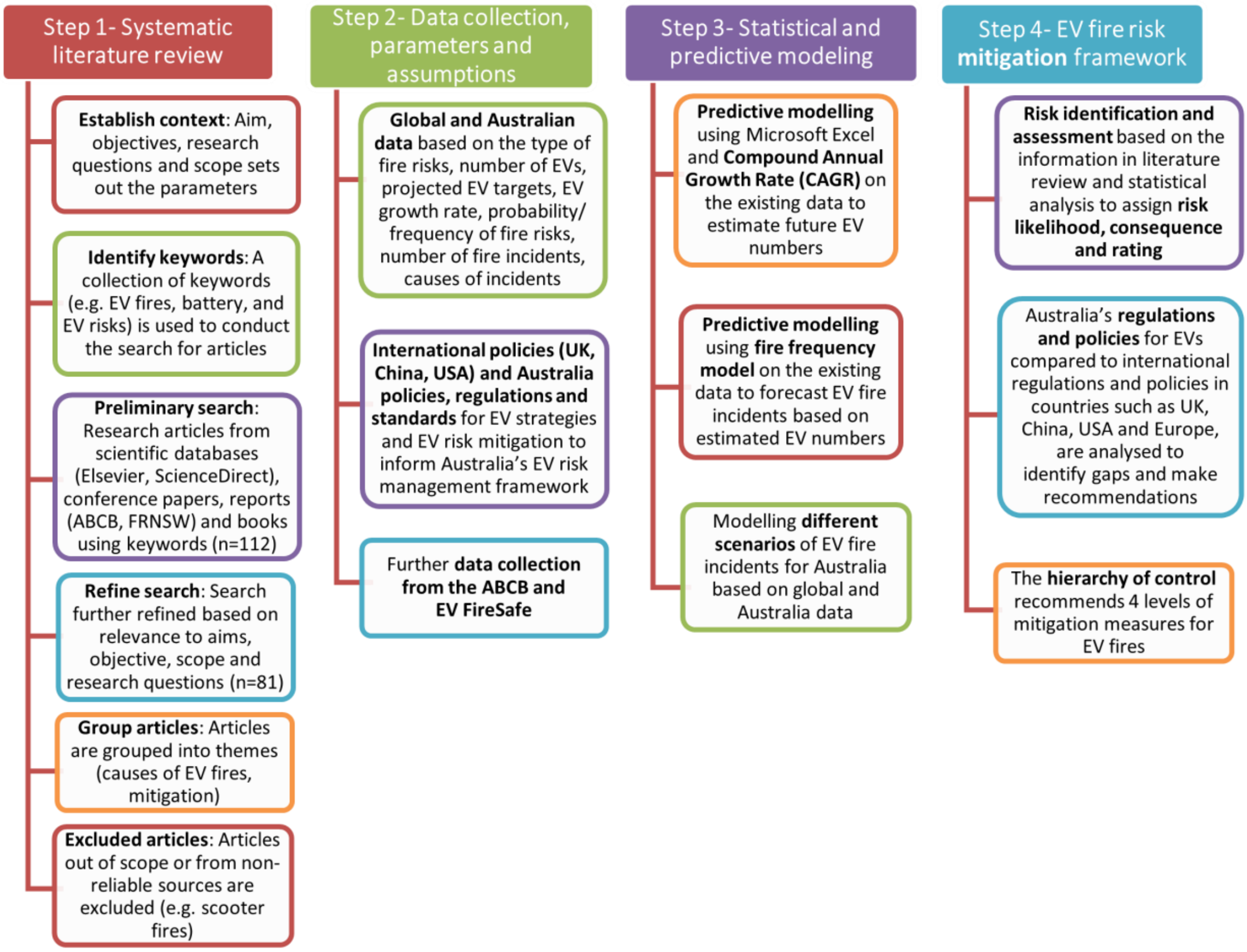

Figure 1. Steps of systematic literature review to mitigation framework.

The research methodology for forecasting EV fire incidents for Australia was based on specific keywords such as EV numbers, ICEV numbers, EV fire incidents globally, ICEV fire incidents globally, car fire statistics, EV fire statistics, ICEV fires in USA, ICEV fires in UK, global EV fire frequency, global ICEV fire frequency, fire frequency, causes of EV fires, and EV strategies for Australia. These keywords were chosen to screen data sources and articles based on the critical criteria and relevance to the main aim and objectives, including research questions related to statistical data for EV fire incidents and forecasted EV fire incidents for Australia. This section builds on the predicted analysis in Section 3.1 for EV numbers in Australia. The methodology for forecasting EV fire incidents in Australia is summarised in the steps 2 and 3 of Figure 1.

2.1.1. Current EV Numbers in Australia and Globally

Graphical representations of the growth in EV numbers in Australia and globally using current data are shown in Figure 2. The global data trend shows the change in EV numbers from 0.37 million in 2011 to 22.5 million EVs in 2022 [7]. Figure 2 also indicates that the number of EVs in Australia increased from 49 EVs in 2011 to 83,000 EVs in 2022 [8]. The growth in EV numbers (3.8% annually) for Australia is significantly lower compared to global numbers (14%) in 2022 due to fewer EVs entering Australian markets and low EV uptake in the initial years [8,9]. Estimates by Bloomberg show Australia is roughly five years behind Europe and the USA while lagging around ten years behind China. The global stock of EVs is predicted to reach 116 million units, which is 60% of total sales by 2030, to achieve net zero CO_2 emissions by 2050 [9]. The exponential growth in EV numbers globally is related to more stringent emission targets, more EV models in the market, enhanced fuel efficiency standards, EV and Li battery supply chain expansions, EV subsidies, tax incentives, or a detailed sales target for emission reduction, and greater charging infrastructure and availability.

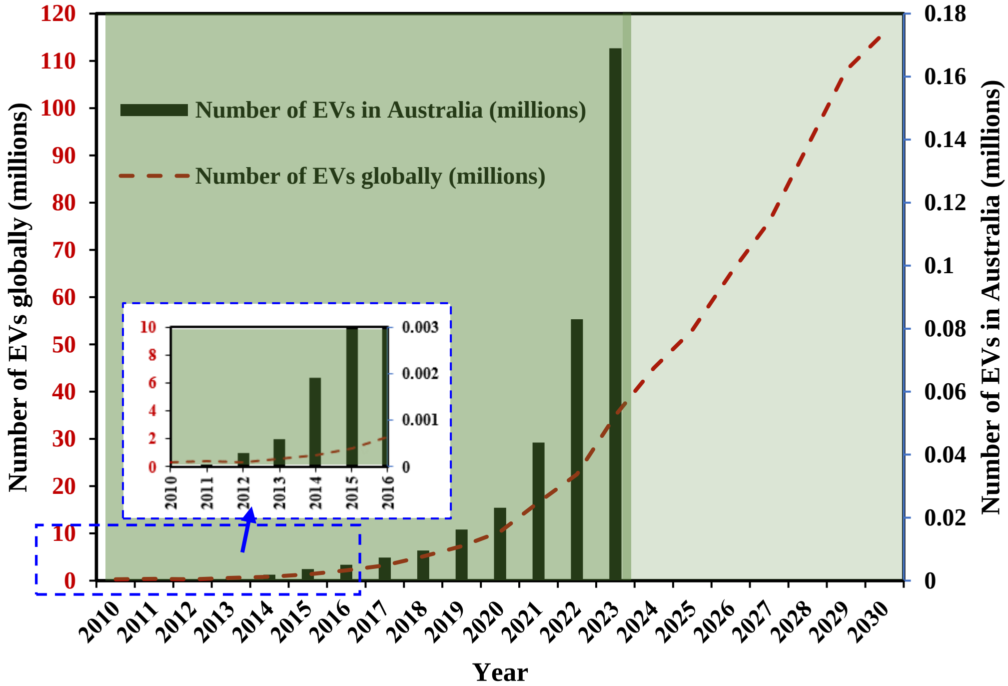

Figure 2. Comparison of current EV data globally and in Australia [7–9].

2.1.2. Comparison of EV Fire Incidents in Australia to Other Countries

Figure 3 shows the comparison of EV fires globally with EV fires in Australia. In Australia, EV numbers are expected to exceed 1 million in 2023 [10]. As EV numbers increase in Australia to a forecast total of 15.8 million EVs by 2050, it is expected that the number of EV fires will increase relative to the increase in EV numbers. Other countries experienced similar trends. For example, the UK experienced a surge in EV fires from 32 fires in 2020 to 102 fires in 2021 as more EVs were introduced into the market [11].

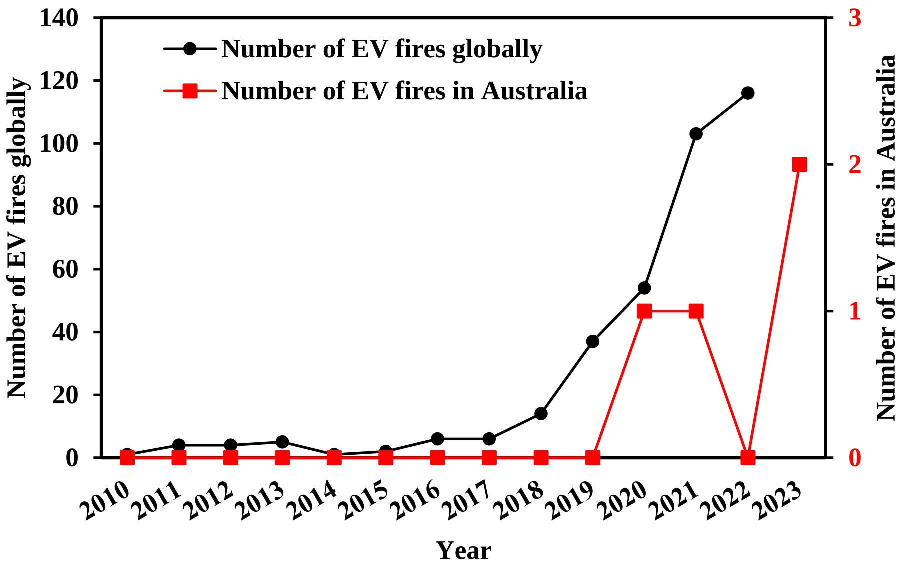

Figure 3. Comparison of EV fire incidents globally and in Australia [11].

Studies conducted in various countries reveal that their annual fire frequencies are comparable to or surpass those of Australia. This can be attributed to the fact that these countries embraced electric vehicles (EVs) during the initial stages when knowledge and awareness surrounding EVs, lithium battery technology, and charging were relatively limited. For instance, Finland encountered three incidents of EV fires during the charging process between 2015 and 2019, leading to an annual fire frequency of 65 fires per million EVs [12]. Despite being derived from a limited dataset, the findings suggest a comparatively low occurrence of EV related fires. Norway, which boasted the highest EV adoption rate globally at 14% in 2018, reports that incidents of EV fires make up approximately 2.3% to 4.8% of vehicle fire insurance claims. Over ten years, the average annual percentage stands at 2.6% [13]. Considering that these figures encompass vehicle fires resulting from collisions, a type predominantly associated with internal combustion engine vehicles (ICEVs), it implies that electric vehicle (EV) fire rates are lower in comparison. In China, which boasts the largest EV market globally, an average of 31 incidents of Li battery fires are reported annually. Among these, the majority are sudden ignitions (36.9%), while a significant portion occur during the charging process (26.2%) [14]. In the United States, the National Transportation Safety Board (NTSB) has reported 17 Tesla and 3 BMW i3 LIB fires out of 0.35 million and 0.1 million vehicles, respectively [15]. This equates to an EV fire frequency of 44 fires per million vehicles, although the period over which these incidents occurred is not specified [15]. In London, the Fire Brigade dealt with 54 EV fires in 2019 compared to 1898 ICEV fires, with a similar trend observed in 2020 [16]. The proportion of EV fires to all vehicle fires was just 2.7%. However, due to the absence of specific details regarding the causes, locations, and the total number of vehicles in London, it remains to be seen whether EV fires are more or less common compared to fires involving internal combustion engine vehicles (ICEVs) [16].

2.2. Statistical Model and Validation Used for Forecasting EV Numbers

Based on the available baseline data, the statistical analysis employed predictive modelling techniques to estimate the number of electric vehicles (EVs) in Australia. The forecasting feature in Microsoft Excel was utilised to forecast EV numbers for Australia up until 2050. However, there needed to be more data regarding estimated EV numbers beyond 2022. The choice to use Excel's forecasting tool was made due to its reputation for reliability, as it leverages statistical algorithms and methodologies to analyse historical data and make predictions for future values [17]. This method included exponential smoothing, moving averages, regression, and time-series analysis. Additionally, it considered the accuracy of forecasted data by comparing the predicted values with the actual values [17]. The accuracy of the forecast also depended on the assumptions and limitations of the forecasting method used and the quality of data used as input [17]. The forecasting function in Microsoft Excel was used in other research fields, such as population growth models and other predictive modelling [17].

The utilised tool relied on a representative dataset from 2021 and 2022, which exhibited a remarkable surge in electric vehicle (EV) sales. Data from 2011 to 2020 was disregarded as the growth rate of EV numbers during that period was modest due to limited adoption and a scarcity of available EV models. Consequently, it not needed to accurately reflect Australia's growth trajectory. The forecasting model incorporated several assumptions, including using Australian Bureau of Statistics (ABS) data, which indicated that there were approximately 20.1 million registered motor vehicles as of 31 January 2021 [18]. Also, passenger vehicle registrations increased by 1.2% [18]. Additionally, 1.2 million cars are expected to be sold in 2023 as per expert opinion [19]. The ten-year average car sales statistics between 2011 and 2020 showed a yearly average of 1.12 million vehicles [20]. The forecasted values represented a 95% confidence interval, reflecting the random error in the sample and providing a range of values likely to include the unknown parameters.

The model also used a conservative Compound Annual Growth Rate (CAGR) to forecast EVs for 2050 (Equation (1)) based on historical EV trends and targets set for Australia [8,9].

$$CAGR = (Ending\ Value/Starting\ Value)\hat{}(1/Number\ of\ Years) - 1 \quad (1)$$

Over the 2016–2021 period, EV sales in Europe increased by a CAGR of 61%, which was the world's highest, above China (58%) and the United States (32%) [9]. Global EV trends showed that in 2021, EV sales accounted for 9% of the worldwide car market, which is expected to reach 60% by 2030 [9]. In 2022, global sales were 14%, while Australia lags behind other countries with EV sales of 3.8% of the Australian market [8]. At present, Australia's EV statistics is one third (3.8%) when compared to 14% of global EV sales [9]. Therefore, 20% was chosen for Australia's CAGR, a conservative assumption equating to one-third of the overall global EV sales (i.e., 60% CAGR). The CAGR method was used to validate the end values for 2050 over a 28-year period, and these values were compared against the forecasted numbers and targets set in various EV strategies in Australia. Figure 4 shows the percentage error used to evaluate the accuracy of this forecasting model and compares the predicted values generated by the model to the targets. The forecasted EV numbers in this model align with the targets set by CSIRO, the National Electric Vehicle Strategy, Australia's Emissions Projections, and the Future Fuels strategy. The percentage error decreased from 6.7% to 3.3% from 2030 to 2050 as more data was incorporated, demonstrating the model's reliability and accuracy.

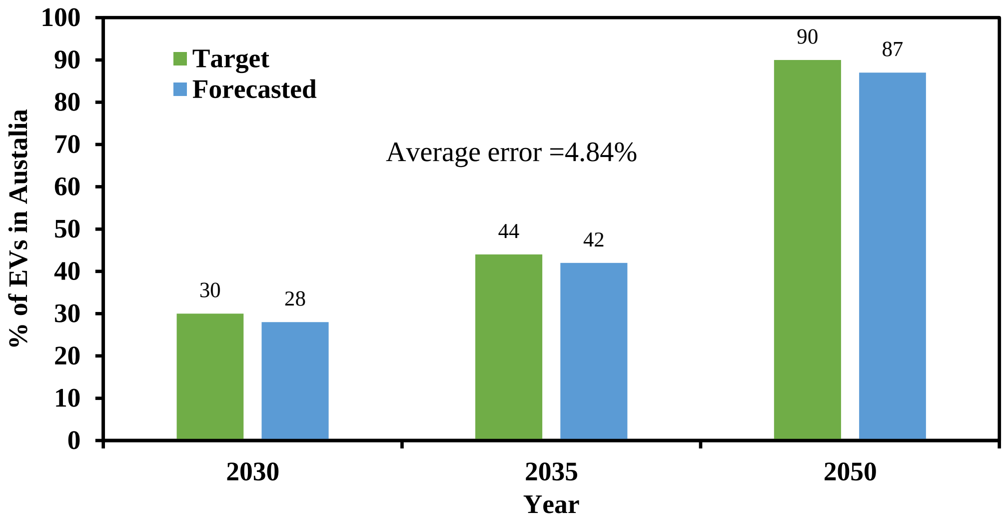

Figure 4. Validation of forecasted numbers against targets in Australia's EV strategies.

2.3. Fire Frequency Model and Validation Used for Forecasting EV Incident Numbers

The statistical analysis used predictive modelling on the existing baseline data and estimated EV numbers to estimate future fire events with EVs for Australia. There is a need for additional data on estimated fire incidents and risks beyond 2022. Fire frequency was the main formula to forecast EV fire incidents in Australia. Fire frequency was calculated based on the number of fires within a specific period of time, i.e., one year. In this study, the fire frequency was calculated by dividing the number of EV fires per year based on the estimated number of EVs in that particular year [21].

$$Fire\ frequency = \frac{number\ of\ EV\ fires\ per\ year}{number\ of\ EVs\ \text{in that perticular year}} \quad (2)$$

Fire frequency was used to estimate fire incidents for EVs because it is a statistical measure that indicates how often a particular event, such as a vehicle fire, is likely to occur within a given period [21]. By analysing historical data on fire incidents and their frequency, researchers can estimate the likelihood of fire incidents occurring in EVs [21]. EVs use high-voltage battery systems and other electronic components that have the potential to overheat and cause fires and understanding the frequency of such incidents is essential for identifying potential safety risks and developing appropriate safety measures. Fire frequency data can help manufacturers, regulators, and other stakeholders evaluate the safety of EVs and implement measures to mitigate fire risks [21]. This method was also used for the National Fire Incident Reporting System (NFIRS) maintained by the United States Fire Administration (USFA), the National Highway Traffic Safety Administration (NHTSA), and the EV Fires database of the European Union (EU), which collects information on all fire incidents, including those involving EVs [21].

Two distinct scenarios were employed to estimate the occurrence of electric vehicle (EV) fire incidents in Australia. In the first scenario, the global average EV fire frequency was utilised, drawing from 12 years of global incidents. This enabled estimating the annual number of EV fires in Australia until 2050. The second scenario considered the average EV fire frequency specific to Australia, taking into account the reported EV fire incidents within the country up to the present time. This approach allowed for a comparative analysis with fire frequency data for ICEVs and EV fire frequencies observed in other countries. This comparative analysis aids in providing context to the risk of EV fires and serves as a foundation for evaluating the overall safety of electric vehicles.

A comparison was conducted between global and Australian data to validate the model, as depicted in Figure 5. For instance, when the number of EVs reached 7.2 million, there were 37 global fires, and the estimated EV fires in Australia was 37 for scenario 1 and 42 for scenario 2. Similarly, with 10.1 million EVs, there were 54 global fires, and the estimated EV fires in Australia for scenarios 1 and 2 were 54 for 60, respectively. However, as the number of EVs reached 16 million, the estimated range for EV fires in Australia was lower, ranging from 84 to 95 fires. In contrast, globally, there were close to 103 fires reported for a similar number of EVs. This disparity could be attributed to the slower uptake and transition period for EV adoption in Australia and advancements in technology, standards, and compliance requirements, which likely contribute to improved safety measures.

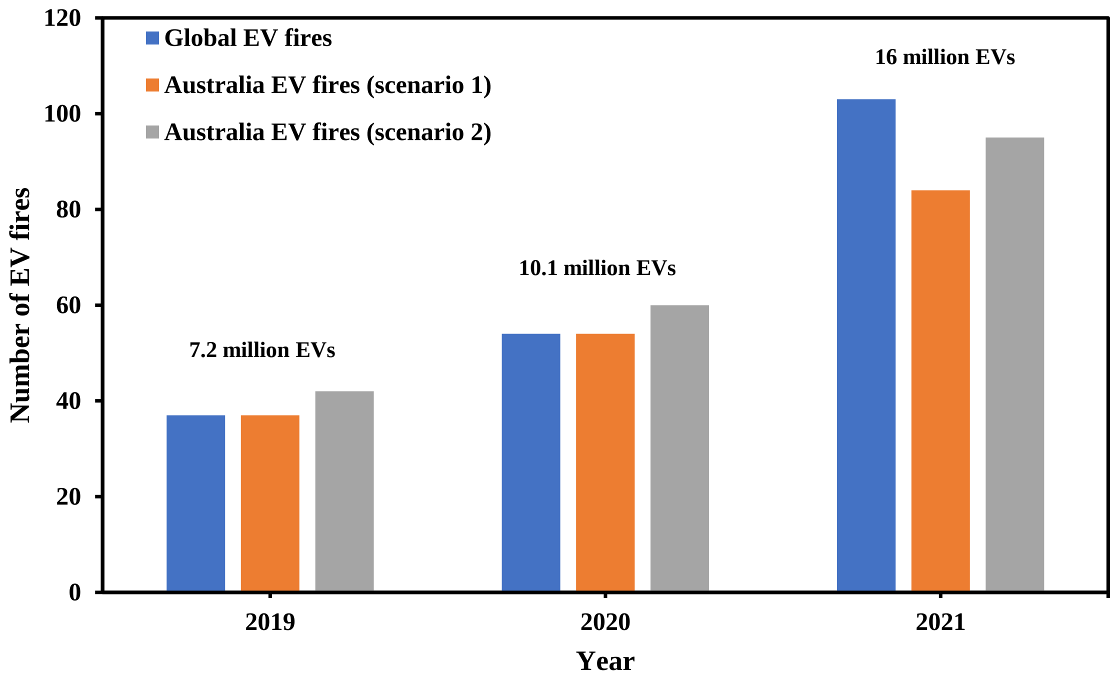

Figure 5. Validation of Australia's EV numbers against similar global EV numbers.

2.3.1. Current EV Fire Incidents with Growth in EV Numbers Globally

Graphical representation of EV numbers and EV fires globally between 2010 and 2022 are shown in Figure 6. In recent times, the percentage of fires increased from 1.4% (6 fires) in 2017 to 2.5% (37 fires) in 2019 to 9% (103 fires) in 2021 and 10% (116 fires) in 2022 [8]. During this period, EV numbers were seen to increase globally from 3.2 million (2017) to 7.3 million (2019) to 16.5 million (2021) and 22.5 million (2022) [7]. In the early years between 2010 and 2013, when there were less than 0.5 million EVs globally, the percentage of EV fires was less than 0.5% or no more than five fires [7]. Between 2013 and 2017, EV numbers increased from 0.8 million to 2.2 million, and the percentage of fires was less than 1% [10].

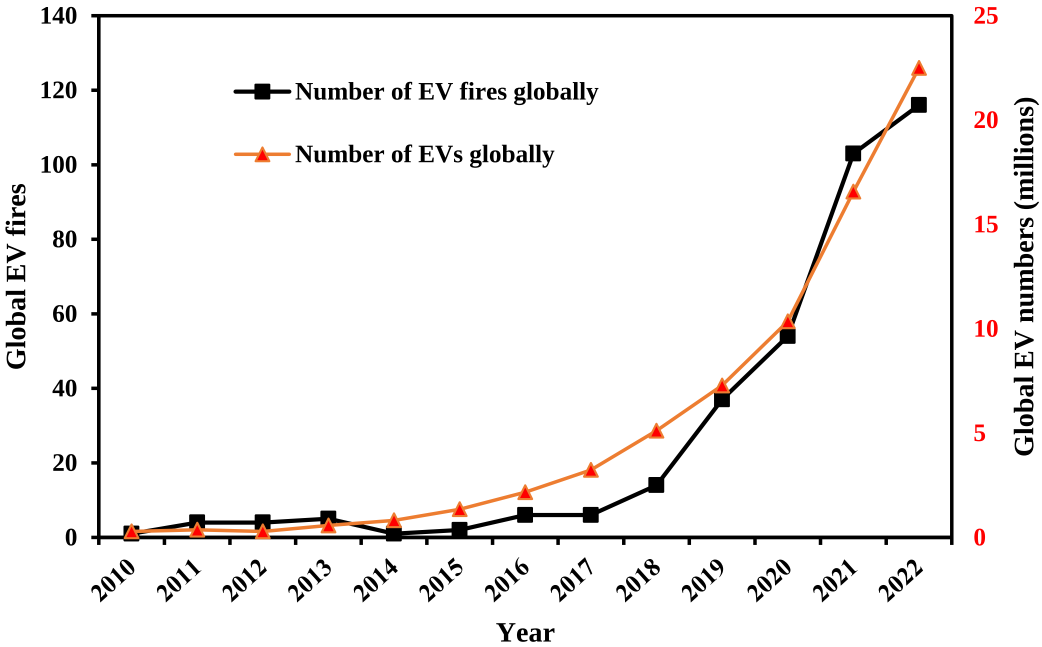

Figure 6. Global comparison of EV numbers and EV fires [7,10].

Fire frequency is calculated by dividing the number of EV fires per year based on the number of EVs per year [21]. The average global EV fire frequency between 2010 and 2022 is 5.29 fires per million EVs. The global EV fire frequency changed from 1.85 fires per million EVs in 2017 to 5.1 per million EVs in 2019, then to 6.2 per million EVs in 2021 and finally to 5.2 per million EVs in 2022. During 2011 and 2012, the fire frequency was higher, 10.8 fires per million EVs and 14 fires per million EVs, respectively, which could have been due to EVs being new to the market, less research and knowledge of EV fire risks, fewer fire mitigation measures, and a lack of awareness, training, and education on handling EVs including Li batteries and EV charging.

2.3.2. Current EV Fire Incidents with Growth in EV Numbers for Australia

Figure 7 compares the growth in EV numbers with EV fire incidents in Australia using current data. No EV fires were recorded between 2011 and 2019 in Australia [10]. There was one EV fire in 2020 when EV numbers were 23,000, one EV fire in 2021 when EV numbers were 43,800, and two fires for the first quarter of 2023 when EV numbers are expected to exceed 100,000 in Australia [10]. On 25 February 2020, NSW reported a Tesla model 3 EV fire [8]. On 28 February 2021, there was one EV fire reported for QLD involving a Tesla [10]. Between January and March 2023, NSW reported an EV fire involving a Tesla S, Tesla 3, and a Toyota Prius and another fire with a converted EV [10]. EVs, including heavy-duty vehicles, bikes, or scooters, are not included in this dataset as they have been excluded from this research. Based on the reported EV fires, the average EV fire frequency for Australia between 2011 and 2023 is six fires per million EVs in Australia. This is close to the global average fire frequency of 5.29 fires per million EVs. However, as EV numbers increase and more education, training, awareness, and safety measures are introduced, such as thermal sensors, enhanced BMS, manufacturing standards, compliance rules, and standards for chargers, the fire frequency in Australia is expected to decrease.

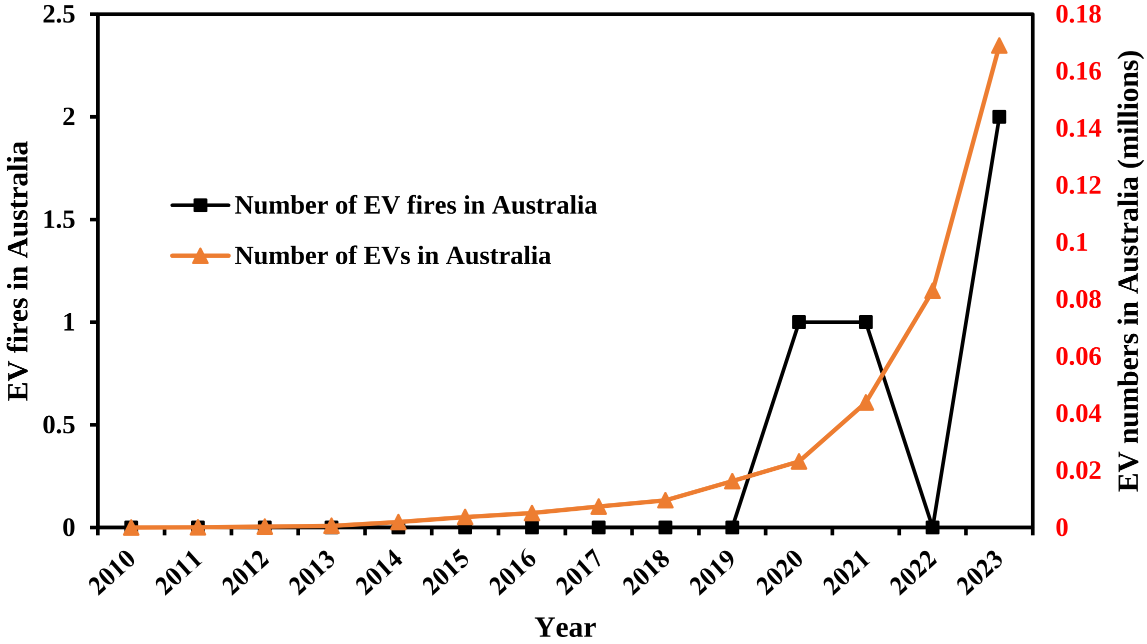

Figure 7. Comparison of EV numbers and EV fires for Australia [8,10].

3. Predicted EV Numbers and EV Fire Incidents by 2050

3.1. Predicted EV Numbers for Australia

Based on Figure 8, it is evident that there needs to be more data available on forecast EV numbers for Australia. As a result, a model was developed to predict EV numbers. Figure 8 shows the forecast growth in EV numbers from 2023 to 2050 for Australia and compares the forecasted numbers to targets set in various Australian government reports. The EV numbers for Australia increase from 0.044 million, which is 2.05% in 2021, to 0.083 million, which is 3.8% in 2022, and is expected to exceed 0.1 million in 2023. EV sales for the first quarter in Australia for 2023 tallied 17,396 units [22]. Based on the forecast model, Australian EVs are expected to grow to 1.73 million units by 2030, which represents 28% EVs in Australia, then 3.92 million units by 2035 or 42% EVs in Australia and 15.8 million units by 2050, which represents 87% EVs in Australia. These projections are consistent with the projected target of 30% EVs in Australia by 2030, which translates to over 1.7 million EVs on the roads as the target set in DISER's Future Fuels Strategy [23] and 44% in 2035 in DCCEEW's Australia's Emissions Projections report [24] on the basis that EV strategies will increase EV uptake and exceed projected numbers. The previous Australian Government [25] and CSIRO [26] modelling predicted that close to 90% or approximately 18 to 20 million EVs will be on Australian roads by 2050. The forecasting model demonstrates in Figure 8 that there will be a total of 15.8 million EVs in Australia by 2050, which is 87% of EVs on Australian roads and near the predicted targets set in various EV research work and strategies. These EV numbers are likely to change as more EV models become available, more incentives and rebates are provided to stimulate EV uptake, and Australia develops a fuel efficiency standard. It will also introduce other measures, which are described in Section 4.

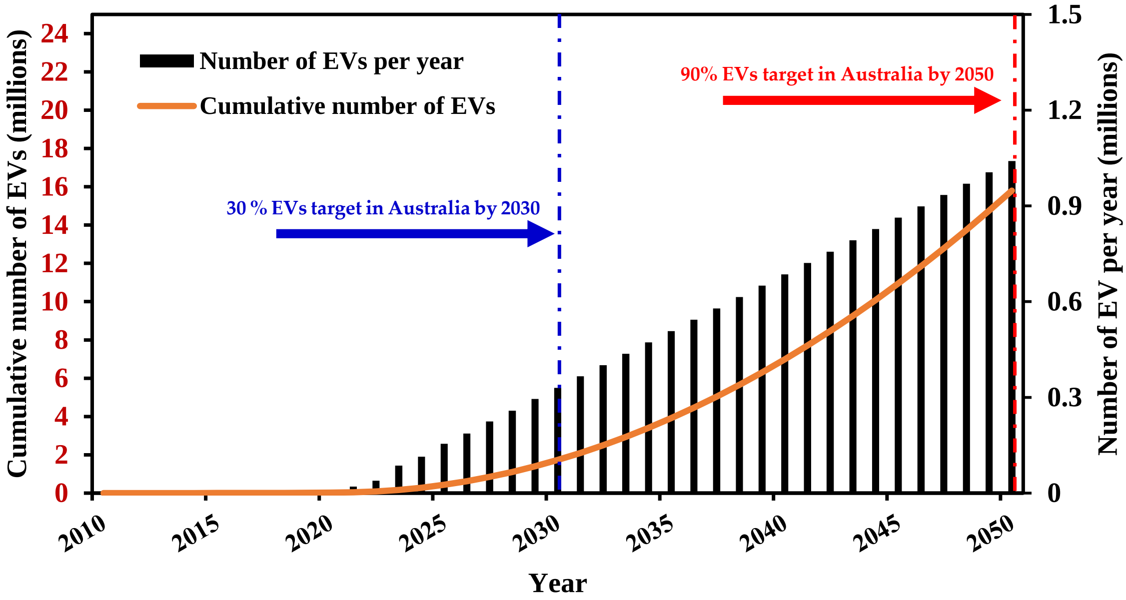

Figure 8. Predicted EV numbers for Australia by 2050.

3.2. Predicted EV Fire Incidents in Australia

This section presents the detailed results of the study, encompassing statistical data, predictive analysis, and comparative analysis of electric vehicle (EV) fire incidents both globally and in Australia, projected up to the year 2050. These results are significant for fire response operations, including the fire brigade, fire industry, and governmental entities. They aid in comprehending the expected increase in fire incidents with the growing adoption of EVs and assist in developing appropriate fire response operations and mitigation measures to effectively address EV fire incidents.

Considering the need for existing data for forecasting future EV fire incidents specifically for Australia, a model was developed to fill this gap. Figures 9 and 10 showcase the forecast EV fire incidents up to 2050 based on projected EV numbers for Australia under two distinct scenarios. In the first scenario, the data estimates an average EV fire frequency of 5.29 per million EVs, derived from global fire incidents between 2010 and 2022. This translates to 34 EV fires anticipated for Australia by 2030 and a cumulative total of 874 fires projected between 2023 and 2050. When the number of EVs reaches 1.73 million in 2030, an estimated nine EV fire incidents are expected in that year. By 2040, with approximately 7 million EVs, an annual estimated 37 EV fire incidents are then projected. Finally, when the number of EVs reaches 15.8 million in 2050, an annual estimated 84 EV fire incidents are anticipated.

In the second scenario, the model estimates an average EV fire frequency of six fires per million EVs, based on reported EV fire incidents in Australia from 2010 to March 2023. This results in a total projection of 41 EV fire incidents by 2030 and a cumulative total of 989 fires between 2023 and 2050. When EV numbers reach 1.73 million in 2030, an annual estimated 10 EV fire incidents are predicted in that year. By 2040, with approximately 7 million EVs, an estimated 42 EV fire incidents are projected. Lastly, when the number of EVs reaches 15.8 million in 2050, an annual estimated 95 EV fire incidents are expected.

Both scenarios illustrate an exponential growth in EV fire incidents, with a fourfold increase projected between 2030 and 2040, followed by a doubling of EV fire incidents between 2040 and 2050. The slight variance in EV fire incidents and frequency between the two models can be attributed to the low number of EVs in Australia and the limited number of recorded EV fire incidents from 2020 to Q1 2023.

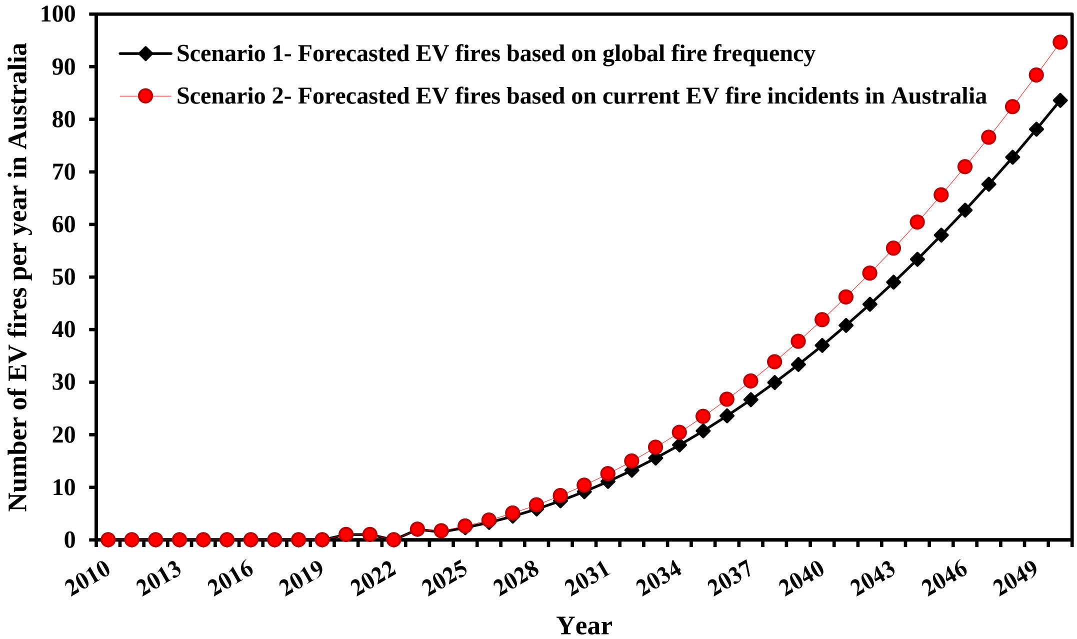

Figure 9. Forecasted EV fire incidents for Australia based on two scenarios.

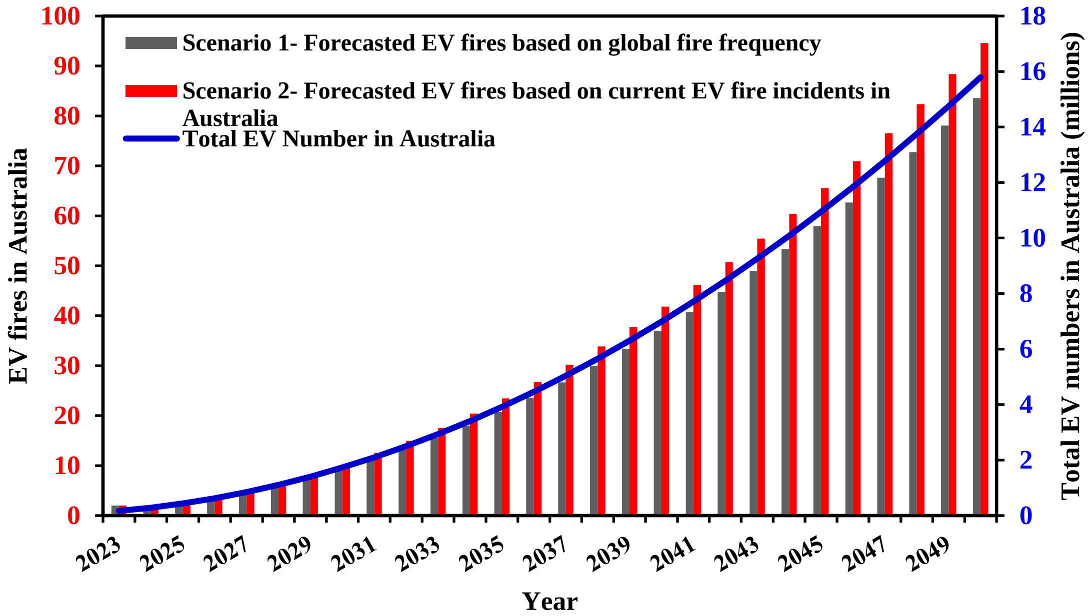

Figure 10. Comparison of forecasted EV fire incidents with forecasted EV numbers in Australia.

It is worth noting that globally, there have been 353 EV fires over 12 years from 2010 to 2022, based on a total of 22.5 million EVs. Therefore, the projection of 874 or 989 fires over 28 years seems reasonable. Furthermore, the validation of the model aligns with the actual figures. For instance, when EVs reached 7.2 million globally, there were 37 global fires, and the model estimates 37 to 42 EV fires in Australia if Australia reaches 7.2 million EVs. Similarly, with 10.1 million EVs, there were 54 global fires, and the model forecast 54 to 60 EV fires in Australia if Australia reaches 7.2 million EVs. Additionally, in 2022, there were 103 fire incidents globally with 16.5 million EVs, which is higher than the estimated 84 to 95 fire incidents for Australia with an estimated 16 million EVs. This difference may be attributed to the possibility of improved technology, systems, and compliance regulations in Australia by the time the country reaches 16 million EVs. It is anticipated that the risk of EV fires, including EV fire incidents and the average EV fire frequency for Australia, will continue to decrease over time as the industry moves towards improved technology, including solid-state batteries and develops technology that is less vulnerable to "thermal runaway" and other related catastrophic events [27]. DCCEEW's National Electric Vehicle Strategy [28] is also expected to explore various educational options, including safety and security standards for EVs. The present forecast for EV fire incident data hold particular significance for fire response operations, including the preparedness and capacity of the fire brigade to EV fire incidents effectively.

4. Strategies for Promoting EV's Adoption in Australia

The successful adoption of electric vehicles (EVs) in Australia will play a pivotal role in achieving predicted targets related to emissions reduction and sustainable transportation. However, several barriers currently hinder the widespread adoption of EVs, including challenges in charging infrastructure, EV availability and affordability, regulatory standards, and consumer awareness. This section will explore the strategies that can be implemented in Australia to overcome these barriers and drive the transition towards a clean and electric future.

4.1. Charging Infrastructure

One of the key challenges for EV uptake will be ensuring the availability of robust and widespread charging infrastructure. In the coming years, significant efforts will be made to expand the charging network across Australia. By the projected timeline, the Government aims to establish a national EV charging network through the Driving the Nation Fund, with charging stations strategically placed at intervals of approximately 150 km along major roads. This initiative aims to address the current limitations and meet the growing demand for EV charging arrangements. As of the end of June 2022, 2147 public charging locations and 3669 public EV chargers were already in use, marking a 15% increase from early 2021.

4.2. EV availability and Affordability

Ensuring the availability and affordability of EV models will be crucial for their widespread adoption in the future. Australia will continue to work towards expanding the range of available EV models, providing consumers with more options to choose from. As of now, there are 45 models of EVs with a total of 95 variants available in Australia. Additionally, the Government will introduce various incentives and support mechanisms to make EVs more affordable. These measures will include rebates, zero-interest loans, and discounts on stamp duty and registration fees. Such initiatives aim to reduce upfront costs and make EVs a viable choice for a larger segment of the population.

4.3. Regulatory Standards

To facilitate the production and supply of efficient and sustainable vehicles, Australia needs to actively work towards implementing mandatory national vehicle fuel efficiency standards in the future. These standards will set average efficiency targets for vehicles sold by each manufacturer. Introducing such standards will encourage car manufacturers to produce more fuel-efficient petrol, diesel, and EV models. Over 80% of cars sold globally are now covered by enhanced fuel efficiency standards. By embracing these regulatory standards, Australia aims to foster the availability of a broader range of EV models in the market, ensuring that consumers have ample choices and promoting a shift towards cleaner transportation options.

4.4. Consumer Awareness and Education

Raising consumer awareness and education about the benefits and realities of driving EVs will be paramount in driving their acceptance and adoption. In the future, the Australian Government will need to provide extensive education and awareness programs to inform the public about the advantages of EVs. These initiatives will highlight the environmental benefits, lower operating costs, and the potential to use renewable energy sources for charging. By addressing common misconceptions and concerns, these programs will create a positive perception of EVs and encourage their uptake among consumers.

4.5. Collaboration and Funding

Successful implementation of strategies to address barriers to EV uptake will require collaboration between different stakeholders, including governments, industry players, and communities. In the future, the Australian Government will likely facilitate increased collaboration and coordination to improve the consistency of public charging infrastructure, enhance EV affordability and choice, and reduce transport emissions. Partnerships will involve leveraging grants from the Australian Renewable Energy Agency (ARENA) and finance from the Clean Energy Finance Corporation (CEFC) to support EV-related projects and initiatives. Implementing the National Battery Strategy, for example, is expected to create around 35,000 jobs and generate $7 billion in value across all sectors.

Through the implementation of future-oriented strategies, Australia aims to address the barriers hindering EV uptake and achieving its predicted targets for a cleaner and greener transportation system. Expanding charging infrastructure, increased availability and affordability of EV models, implementation of regulatory standards, and robust consumer awareness programs will collectively drive the transition towards a sustainable, low-emission future. By taking proactive measures and fostering collaboration among stakeholders, Australia will pave the way for widespread EV adoption, contributing to reducing greenhouse gas emissions and achieving long-term sustainability goals.

5. Risk Mitigation Framework

A risk mitigation framework is a structured approach used to identify, assess, prioritise, and manage risks (Figure 11). It provides a systematic process for developing and implementing strategies and actions to minimise, control, or transfer EV fire risks and their potential consequences [29]. By implementing an EV fire risk mitigation framework, governments, policymakers, fire engineers, and fire authorities can proactively manage and reduce exposure to potential EV fire risks and consequences [29]. The recommended mitigation measures, capacity, and capability to deal with anticipated EV fire incidents in Australia are discussed below:

5.1. Identify the Risk

This section identifies the key risks foreshadowed by the increased EV numbers in Australia. As indicated in Sections 3.1 and 3.2, Australia is estimated to have approximately 84 to 95 EV fire incidents as EV numbers increase to 15.8 million in Australia by 2050, and these EV fires can be the causes of various fire risks. The risks associated with EV fires include occupant safety, Li battery short circuit, overheating, overcharge, rapid charging, poor battery manufacturing, poor installation of batteries, improper EV repair and maintenance, thermal impact, electrical impact damage, and mechanical impact through penetration or other physical consequences. The EV fire risks are identified and addressed in the risk assessment approaches, which are discussed in Section 5.2.

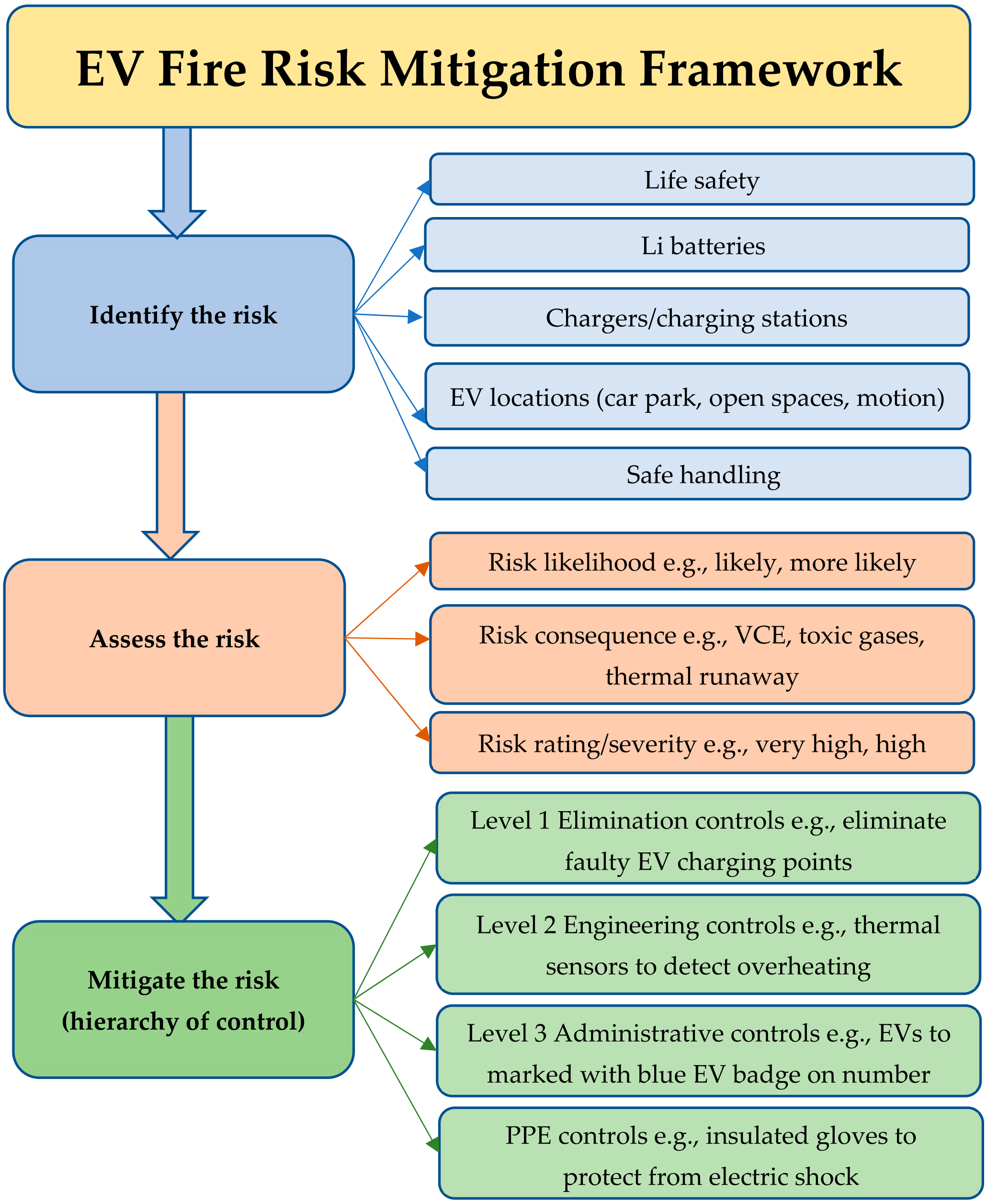

Figure 11. EV fire risk mitigation framework.

5.2. Assess the Risk

Assessing the EV fire risk means determining how likely it is that a consequence will harm someone and how serious that threat could be [30]. A risk assessment identifies the nature of the risk, the likelihood, and consequences in relation to EV fire risk [30]. Risk likelihood is the probability or possibility of a hazard or unfavourable consequence. This measure can be conveyed qualitatively, using descriptors like rare, likely, certain., etc., or quantitatively, using probabilities or frequencies [31]. Risk consequence refers to the outcome or result of an adverse event or hazard. In this study, hazard is defined as something that could potentially cause harm. It encompasses the impact and severity of the harm or damage that occurred and may include property damage, financial loss, injury, or loss of life [31]. By considering both the likelihood and consequence of a risk, informed decisions are made on prioritising and allocating resources to manage and mitigate EV fire risks [31]. Risk severity is the potential impact or consequences of an adverse event or risk on a system, project, or individual while considering likelihood, vulnerability, and criticality [31]. The severity of a risk is often measured on a scale, which can be qualitative (e.g., low, medium, or high) or quantitative (e.g., numerical values). For example, an EV fire in a building can have different consequences, such as property damage, injury, or loss of life. However, the severity of these consequences can vary depending on the size and intensity of the fire, the number of people present, and the level of preparedness and response [21]. The risks and a risk rating are assigned based on statistical and anecdotal evidence, such as 0–5% is considered to be low; 5–10% moderate; 10–20% high; and above 20% is very high [10,32]. Risks more significant than 50% are considered extreme; although no EV fire risks have been identified for this category.

5.3. Control/Mange the Risk

Risk mitigation involves developing and implementing strategies and actions to minimise or control the identified EV risks through risk reduction, risk sharing, or risk transfer. The hierarchy of control is a system for controlling EV risks in order of effectiveness, which has been used for this EV fire risk mitigation framework [30]. It includes different approaches, which may be used in combination, with the highest level of control, including avoiding or eliminating the risk and reducing the risk through engineering controls (mitigation) and then through administrative and personal protective equipment (PPE) controls [30] as follows:

- Level 1 Eliminate the risk—This control eliminates the EV fire risk entirely and offers the highest level of protection [20]. This is seen as the most effective control measure, e.g., eliminating faulty EV charging points.
- Level 2 Engineering controls—Engineering controls reduce the EV fire risk through engineering changes or system changes, e.g., EV charging stations in buildings are classified as 'Special Hazard' in through building codes with compartmentation or fire suppression systems [33]. These controls protect workers, the environment, or the general public from potential risks associated with a particular process, task, or activity [30].
- Level 3 Administrative controls—These control measures rely on human behaviour and decision making, including supervision, to reduce the risk, and when used on their own, tend to be the least effective in minimising risks [30], for example, emergency planning or other operational protocols.
- Level 4 PPE controls—PPE controls refer to using protective equipment to reduce the risk of workplace injuries or illnesses. PPE controls are often used as a last line of defence after other engineering and administrative controls have been exhausted or are not feasible. PPE controls can effectively protect workers from hazards such as flying debris from an EV fire and loud noise. However, they are not foolproof, and workers must be adequately trained in their use and maintenance to ensure they provide adequate protection [26].

6. Conclusions

This study has projected the future growth of EV numbers in Australia, estimating that by 2030, there will be approximately 1.73 million EVs on the roads, increasing to 15.8 million by 2050. These projections align with the targets outlined in various EV strategies for the country. Additionally, the research has estimated the frequency of EV fire incidents in Australia, indicating an expected range of 9 to 10 EV fire incidents annually in 2030, 37 to 42 EV fire incidents annually in 2040, and 84 to 95 EV fire incidents annually in 2050.

Comparing the average global EV fire frequency of 5.29 fires per million EVs, the study reveals that the average EV fire frequency in Australia is higher, standing at six fires per million EVs. Notably, this average EV fire frequency is significantly lower than the average fire frequency for all vehicle fires in Australia, which is reported to be 2130 fires per million vehicles. It is important to note that this vehicle data includes all vehicle fuel types and causes of vehicle fires, including arson, and considers that there are currently more gasoline vehicles on the roads than EVs.

In summary, this study provides valuable insights into the barriers to EV uptake in Australia and the achievement of predicted targets. The research offers a comprehensive understanding of the challenges and opportunities in the EV sector by identifying the key EV fire risks, projecting future EV numbers, and estimating EV fire incidents. These findings contribute to developing a robust EV fire risk assessment and control framework and reinforce the potential for EVs to play a significant role in Australia's sustainable transportation future.

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