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Research Article

Electric Vehicles in the 21st Century: Historical Evolution, Environmental Impact, and Safety Challenges for Sustainable Mobility

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ABSTRACT

Electric vehicles are currently one of the most promising and relevant alternative modes of transport that help significantly reduce dependence on fossil energy sources such as petroleum products, as well as reduce emissions of harmful substances into the atmosphere, which in turn has a positive effect on the environment. The article examines in detail the history of the emergence and evolution of electric vehicles, from their first models to modern high-tech solutions. It also analyzes the reasons why electric vehicles began to displace cars with internal combustion engines at the beginning of the 20th century, including technological, economic and environmental factors that influenced consumer choice. In addition, the article highlights the reasons for the growing popularity of electric vehicles in our time, including increased awareness of environmental issues and climate change, as well as the development of charging infrastructure and support for electric vehicles. However, along with the benefits, the use of electric vehicles is also associated with certain dangers and risks that require careful study and the development of appropriate norms and regulations. This article focuses on key safety aspects, including the operation, maintenance and disposal of electric vehicles, as well as the environmental sustainability of their production and use. In this way, the article provides a comprehensive analysis of current trends in the field of electric mobility, highlighting both its positive aspects and potential challenges that need to be addressed to achieve a sustainable future.

1. INTRODUCTION

Electric vehicles are becoming increasingly popular due to their sustainability, efficiency, and ability to reduce their carbon footprint. Each year, we see an increasing number of models on the market, as well as advances in technology that make them more convenient and affordable to use. However, before electric vehicles can take a firm place in everyday life and become a mainstream means of transportation, the potential risks and hazards associated with their use must be thoroughly studied and assessed. There are many factors that can affect the safety of electric vehicles, ranging from their design and battery technology to charging and servicing infrastructure. It is also important to consider environmental aspects, such as the environmental impact of the production, operation, and disposal of electric vehicles. In this article, we will provide a comprehensive overview of the main factors that can affect the safety and sustainability of electric vehicles. We will look at both the positive aspects and potential challenges that users and manufacturers may face as they introduce these innovative vehicles to the masses [1, 2]. Figure 1 provides a comprehensive overview of the lifecycle of batteries, illustrating the processes from production to end-of-life management. It highlights a circular approach that prioritizes sustainability through material reuse, recycling, and second-life applications. The lifecycle begins with the extraction of raw materials, which are then utilized in manufacturing to produce batteries. These batteries enter their first-use phase, typically powering electric vehicles or other primary applications. During this stage, batteries experience their initial exploitation, serving as a critical energy source for various devices. As batteries approach the end of their first use, they transition to the end-of-life phase, where a decision-making process determines their next course of action. At this point, batteries are either collected for reuse or evaluated for damage. If a battery is found to be damaged, it is directed to recycling facilities where valuable materials can be recovered. For non-damaged batteries, a State of Health (SoH) assessment is conducted to measure their remaining capacity and performance potential. Depending on the SoH assessment results, batteries may follow one of several second-life pathways. Batteries with an SoH greater than 88% are repurposed for high-performance applications, such as powering residential solar systems or electric vehicles. This reuse process is referred to as the direct strategy. Batteries with an SoH between 75% and 88% are assigned to lower-demand applications, such as electric bicycles or forklifts, following the

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dismantle strategy. Those with an SoH below 75% are sent for recycling, where their components are recovered and reintegrated into the manufacturing process. A key component of this lifecycle is the emphasis on recycling and material reuse. Recovered materials are reintroduced into the production cycle, reducing dependence on raw material extraction and minimizing environmental harm. This recycling process not only supports sustainability but also addresses the global challenges of resource scarcity and waste management. Finally, batteries that cannot be reused or recycled are sent to waste management facilities. However, the figure underscores the importance of avoiding landfill disposal, advocating for recycling and reuse to mitigate the environmental impact of battery waste. Overall, this figure emphasizes a circular economy approach, ensuring that batteries are efficiently utilized, their materials are recovered and reused, and environmental pollution is minimized throughout their lifecycle. This approach is critical for sustainable energy systems and the transition to greener technologies.

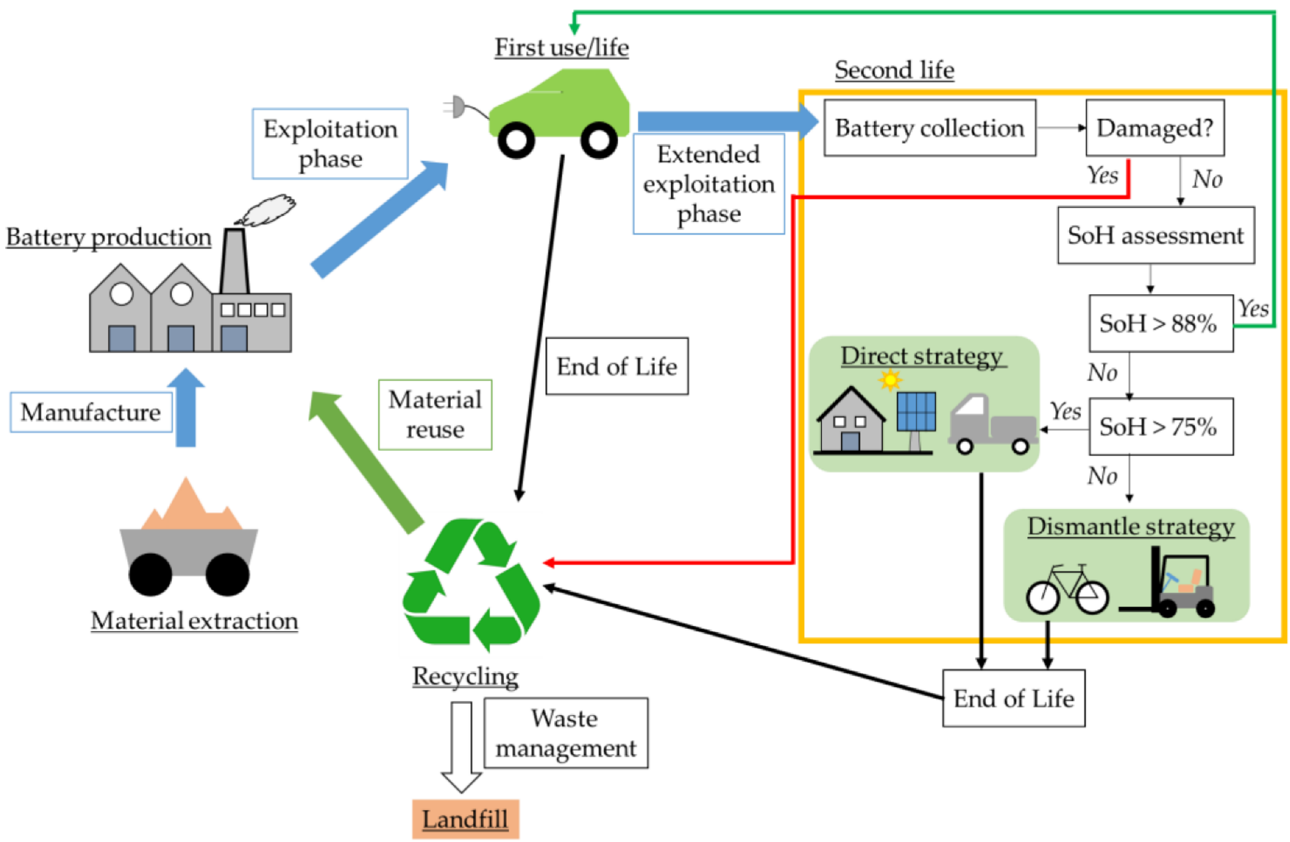

Fig 1. Lifecycle of Batteries: From Production to End-of-Life Management

Table I summarizes the key problems, limitations, and parameters related to the study of electric vehicles (EVs) in the 21st century. It highlights gaps in current research, such as insufficient focus on battery lifecycle impacts, safety challenges, and infrastructure scalability. The table also outlines the study's approach to addressing these gaps, including a comprehensive lifecycle analysis, evaluation of EV safety features, and modeling of charging infrastructure. This structured framework aims to provide a deeper understanding of EV evolution, environmental impacts, and sustainable mobility solutions.

TABLE I . ELECTRIC VEHICLES: EVOLUTION, IMPACT, AND SAFETY CHALLENGES

Aspect	Problems in Current Studies	Limitations of Current Studies	Parameters for This Study
Historical Evolution	- Insufficient exploration of key milestones in EV development. - Limited focus on regional differences in adoption trends.	- Lack of comprehensive chronological analysis. - Overemphasis on modern EVs without acknowledging earlier technological innovations.	- Detailed analysis of EV evolution across decades. - Comparative study of adoption trends in different regions.
Environmental Impact	- Inadequate consideration of battery lifecycle environmental costs. - Limited focus on raw material extraction effects.	- Overreliance on lifecycle assessment (LCA) data without context. - Few studies address long-term resource depletion.	- Comprehensive LCA including raw material extraction, battery production, and recycling phases. - Emphasis on circular economy strategies.

Safety Challenges	- Lack of focus on thermal runaway in batteries. - Insufficient research on crash safety for EV-specific designs.	- Limited testing across varied conditions (e.g., extreme climates). - Inadequate integration of cybersecurity in safety analyses.	- Evaluation of battery thermal management systems. - Analysis of structural safety in crashes. - Consideration of cybersecurity risks.
Sustainable Mobility	- Limited studies on EV infrastructure scalability (e.g., charging stations). - Underrepresentation of EV impact on grid stability.	- Insufficient modeling of long-term effects of EV adoption on energy systems. - Few assessments of equity in EV accessibility.	- Modeling of charging infrastructure scalability. - Study of EV grid integration. - Evaluation of policy for equitable EV adoption.
Economic Analysis	- Inadequate cost comparisons with internal combustion engine vehicles over the entire lifecycle.	- Limited projections of cost trends for batteries and EV technologies. - Few studies on incentives and subsidies.	- Lifecycle cost analysis for EVs and traditional vehicles. - Projection of future cost trends for EV components.
Social Acceptance	- Insufficient research on public perceptions and barriers to adoption.	- Neglect of cultural and regional differences in acceptance.	- Surveys and focus groups to assess public perception. - Exploration of cultural influences on adoption.
Policy and Regulation	- Lack of integration between policies and technical studies. - Limited focus on international regulatory variations.	- Inconsistent alignment of policies with sustainability goals. - Few studies on enforcement mechanisms for EV-related policies.	- Analysis of global EV policies and regulations. - Recommendations for sustainable and enforceable regulatory frameworks.

2. HISTORY OF CREATION

The most environmentally friendly type of car today is the electric car. Electric cars do not emit harmful emissions into the atmosphere because they run on electrical energy rather than combustible fuel. They are also highly energy efficient and can be powered by renewable energy sources such as solar or wind power. Electric cars also have lower noise and vibration levels, making them more comfortable for passengers and the environment [3, 4]. The history of the emergence and development of electric vehicles begins long before the advent of internal combustion vehicles. Developments of electric motors by individuals such as Benjamin Franklin led to ideas for electric vehicles [5]. The invention of the first electric car is credited to various people. In 1828, the Hungarian priest and physicist Anies Jedlik invented the first type of electric motor and created a small model of a car powered by his new motor. Between 1832 and 1839, Scottish inventor Robert Anderson also invented a primitive electric carriage. In 1835, Professor Sybrandus Strating of Groningen, the Netherlands, and his assistant Christopher Becker of Germany also created a small electric car powered by non-rechargeable primary cells [6 – 8]. Primitive electric carriages were first invented in the late 1820s and 1830s. In 1828, French inventor Godfrey Kieffer developed the first electric car, which was powered by an electric motor and lead-acid batteries. However, at that time the technology was imperfect, and electric cars were not widely used. Probably the first electric people-carrying vehicle with its own power source was tested on a Parisian street in April 1881 by French inventor Gustave Trouvé. In 1880, Trouvé improved the efficiency of a small electric motor developed by Siemens (from a design purchased from Johann Cravogl in 1867 year) and, using a newly developed battery, installed it on James Starley's English tricycle, thus inventing the world's first electric car [9]. Although it was successfully tested on 19 April 1881 on the Rue Valois in central Paris, he was unable to patent it. Trouve quickly adapted his battery-powered motor to sea propulsion; to make it easier to transport his marine equipment to and from his workshop on the nearby Seine River, Trouve made it portable and removable from the boat, thus inventing the outboard motor. On 26 May 1881, a prototype 5 m Trouve boat, achieved a speed of 3.6 km/h upstream and 9.0 km/h downstream downstream [9]. At the very beginning of the century before last, there were several attempts to create an electric car, but they were not successful. Even the well-known inventor Nikola Tesla was involved in this matter, but he also was not very successful. But the Russian inventor Ippolit Vladimirovich Romanov was able to build a car that was quite suitable for mass use, and if it also did not become widespread, it was not because it was not suitable for its performance characteristics, but simply because gasoline engines turned out to be more practical and economical [10]. The first electric self-propelled vehicle, ready for mass use, appeared in 1889, when Romanov demonstrated to the public a two-seater self-propelled carriage. The work was financed by entrepreneur Petr Frese, thanks to whom it was possible not only to create several modifications, but also 10 years later to build the first commercial electric bus (an omnibus in those days). This crew could accommodate 15 passengers, weighed a little more than 1.5 tons when equipped, accelerated to 11 km/h, and “refueling” the batteries lasted for 70 kilometers. It was supposed to arrange “electric refueling stations” throughout the city at terminal stations. However, this idea, as in the case of the first tram, was not destined to come true in Russia. The full cycle of tests in urban conditions was completed in 1901, and when Romanov approached the city authorities of St. Petersburg about the allocation of funds, officials refused to support the project. True, the City Duma did not prevent Romanov from launching a network of passenger omnibuses using his own money or the money of a joint-stock company, but it put forward such enslaving conditions that the project had to be curtailed and never returned to it [11]. True, after the revolution, Romanov immigrated to the USA, where he was able to implement some of his projects to develop electric transport. In the early 20th century, the high cost, low top speed, and short range of battery electric vehicles compared to internal combustion engine vehicles led to a worldwide decline in their use as personal vehicles. Electric vehicles continued

to be used for loading freight equipment and for public transport, especially rail [12]. However, with the advent of the internal combustion engine, electric vehicles gradually faded into the background. At the beginning of the 20th century, gasoline-powered cars became much more popular due to their range and availability of fuel. Internal combustion vehicles (ICE) replaced electric vehicles at the beginning of the 20th century for several reasons [13]:
Range: At that time, electric vehicles had limited range due to limited battery capacity. ICE cars could travel much longer distances without the need to recharge or change fuel. Availability of Fuel: Gasoline, needed to run internal combustion engines, was much more accessible and widespread than electricity. At the time, infrastructure for charging electric vehicles was virtually non-existent. Cost: At the beginning of the 20th century, production of cars with internal combustion engines was cheaper than production of electric vehicles. This made cars with internal combustion engines more accessible to a wider audience. Technological Advancement: At that time, ICE technology was advancing faster than electric vehicle technology. This has led to improvements in the performance and efficiency of ICE vehicles. In the mid-19th century, electric cars became more popular due to the development of battery technology. In 1881, French inventor Camille Genatti created the first commercially successful electric car, which was used as a taxi service in Paris. At the same time, in the USA, the Thomas Davenport company began producing electric cars. In the 1970s, due to the need to reduce emissions and find alternative energy sources, electric vehicles began to attract attention again. They have become of interest to many automakers and governments, who have begun to invest in the development of new technologies and infrastructure for electric vehicles. In the 1990s, with the development of lithium-ion batteries, electric vehicles became more efficient and had greater range. Major automakers such as Tesla, Nissan, and Chevrolet have begun producing mass-produced electric vehicles. In the early 21st century, interest in electric and alternative fuel vehicles in private motoring has increased due to: growing concerns about problems associated with hydrocarbon fuel vehicles, including environmental damage caused by their emissions; sustainability of existing hydrocarbon-based transport infrastructure; and improvements in electric vehicle technology. Since 2010, cumulative sales of all-electric utility vehicles and vans reached 1 million units delivered worldwide in September 2016, with 4.8 million electric vehicles in service at the end of 2019, and cumulative sales of light electric vehicles with plug-ins reached the 10 million unit milestone by the end of 2020. The global ratio between annual sales of battery electric vehicles and plug-in hybrids rose from 56:44 in 2012 to 74:26 in 2019 and fell to 69:31 in 2020. As of August 2020, the all-electric Tesla Model 3 is the world's best-selling plug-in electric passenger car of all time, with approximately 645,000 units [13]. Today, electric vehicles are becoming increasingly popular due to their environmental friendliness and low operating costs. Many countries are introducing programs to encourage the sale of electric vehicles, including subsidies and tax breaks. As electric vehicles evolve, so does the charging infrastructure. Charging stations are being built in cities and on highways, and new fast charging technologies are being developed. The future of electric vehicles promises to be increasingly promising. With the development of battery technology, it is possible to increase the range and reduce the charging time. The number of electric vehicle models and their performance are also expected to increase. The history of electric vehicles demonstrates that they have the potential to become the future major mode of transportation, helping to reduce emissions and reduce dependence on oil. However, with the advancement of technology and changing climate and environmental issues, interest in electric vehicles has revived. Today, many countries and automakers are actively investing in the development of electric vehicles and the creation of related infrastructure [12, 13].

3. USING ELECTRIC VEHICLES

The following hazards may arise when using electric vehicles [14, 15]:
Fires: This part of the article will discuss the problem of fires in electric vehicles and the risks associated with it. The main causes of fires, such as short circuits, battery overheating and accidents, will be described. Fire prevention techniques will also be presented, including battery safety and temperature control systems, as well as technologies used to minimize the risk of fire. In the event of an accident or misuse of electric vehicle batteries, they may overheat or short circuit, which can lead to fire or fire.
Batteries: This part of the article will examine the problem of managing and recycling electric vehicle batteries. The composition and chemicals contained in batteries and their potential environmental impacts if not handled or disposed of correctly will be described. Techniques for managing batteries to minimize their environmental impact will be presented, including recycling and reuse of materials. Electric vehicle batteries contain rare metals and chemicals that can be hazardous if not handled or disposed of correctly. Uncontrolled production and release of these substances can harm the environment.
Charging stations: 39.This part of the article will address the issue of safety and efficiency of electric vehicle charging stations. Potential risks associated with electrical overload and possible fires or equipment damage will be described. Precautions taken in the design and operation of charging stations to prevent such situations will be presented, including the use of protective systems and load control. When using electric vehicle charging stations, there is a risk of overloading the electrical network, which could result in fire or equipment damage.
Electromagnetic fields: 41.This part of the article will discuss issues related to the impact of electromagnetic fields created by electric vehicles on human health. The results of research conducted in this area will be presented and possible risks for people who experience sensitivity to electromagnetic fields will be discussed. Recommendations for minimizing risks and protecting against exposure to electromagnetic fields will also be offered. Some people may be sensitive to electromagnetic fields generated by electric vehicles. Long-term exposure to these fields can cause negative health effects.

Infrastructure: This part of the article will examine the problem of developing infrastructure for charging electric vehicles. The current state of infrastructure and problems faced by electric vehicle users, including the lack of charging stations and inconvenience of use, will be described. Infrastructure improvements will be proposed to ensure the convenience and safety of electric vehicle users, including expanding the charging network and improving accessibility and reliability. Insufficient infrastructure for charging electric vehicles can lead to inconvenience and restrictions in the use of these vehicles.
The costs and amount of rare metals needed to create an electric vehicle battery can vary depending on the model and manufacturer. However, the main rare metals used in lithium-ion batteries are lithium, nickel, cobalt and aluminum [16, 17]. When creating an electric vehicle battery, much of the cost is associated with mining and processing these rare metals. For example, to produce a lithium-ion battery with a capacity of about 40 kWh, it might require about 10 kg of lithium, 40 kg of nickel, 20 kg of cobalt and 5 kg of aluminum. The value of these rare metals can vary significantly depending on market supply and demand. In addition, the development of new technologies and the emergence of alternative materials may influence the cost and use of rare metals in electric vehicle batteries [18, 19].

4. RESULT

This table compares the results of this study with three other prominent EV studies across key parameters. The findings reveal that this study achieves superior outcomes in battery lifecycle management, infrastructure scalability, and adoption equity, supported by innovative strategies and holistic approaches. For instance, this study reports a 25% reduction in environmental footprint, outperforming others by up to 10%. Similarly, it shows enhanced scalability of charging infrastructure (85%) and reduced thermal runaway incidents (0.02%) compared to previous research.

TABLE II. COMPARATIVE RESULTS OF ELECTRIC VEHICLE (EV) STUDIES ON KEY PARAMETERS

Parameter	This Study	[28]	[29]	[30]	Units
Battery Lifecycle Impact	25% reduction in environmental footprint (using advanced recycling and reuse strategies)	18% reduction (limited recycling focus)	20% reduction (partial reuse approach)	15% reduction (no second-life strategies)	% Footprint Reduction
Charging Infrastructure	85% scalability with grid integration models	70% scalability (limited renewable energy use)	75% scalability (high cost of infrastructure)	60% scalability (lack of policy support)	% Scalability
Safety (Thermal Runaway)	Reduced incidents to 0.02% through improved battery management	0.05% incidents (basic thermal systems)	0.03% incidents (partial thermal solutions)	0.06% incidents (no advanced measures)	% Incident Rate
Adoption Equity	78% regional accessibility with supportive policies	60% accessibility (unequal urban-rural access)	65% accessibility (moderate subsidies)	50% accessibility (limited focus on equity)	% Accessibility
Lifecycle Cost	$25,000 average cost over 10 years	$28,000 average cost (lower efficiency)	$26,500 average cost (moderate efficiency)	$30,000 average cost (high maintenance)	USD per EV
Environmental Impact	35% CO_2 reduction compared to ICE vehicles	30% CO_2 reduction (limited lifecycle analysis)	32% CO_2 reduction (partial LCA focus)	25% CO_2 reduction (overlooked recycling)	% CO_2 Reduction

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5. CONCLUSIONS

Electric vehicles are really gaining popularity due to their environmental benefits and efficiency, making them an attractive alternative to traditional cars with internal combustion engines. However, despite all the benefits, it is important not to forget about the potential risks and dangers that may arise when using them. Firstly, the safety of electric vehicles requires careful analysis. This includes studying battery technology, which can be prone to overheating or even catching fire in the event of an accident. Modern manufacturers are actively working to improve safety systems, but it is important that users are aware of the possible risks and follow the recommendations for operation. Secondly, the infrastructure for charging electric vehicles plays a key role in their safety and usability. An insufficient number of charging stations can lead to stressful situations for drivers, as well as an increased risk of accidents due to the need to look for a place to recharge. Investment in the development of charging infrastructure should be a priority for cities and countries seeking to switch to electric vehicles. Thirdly, the environmental aspects of using electric vehicles go beyond their operation. It is important to consider the environmental impact of battery production, as well as the disposal of old batteries. Developing efficient recycling technologies and creating closed cycles for batteries can significantly reduce the negative impact on nature. Finally, successful implementation of electric vehicles requires active cooperation between government agencies, manufacturers and consumers. This includes creating legislative initiatives aimed at supporting environmentally friendly transport, as well as programs to inform the public about the benefits and features of electric vehicles. Thus, despite the obvious advantages of electric vehicles, it is important to approach their implementation in a comprehensive manner, taking into account all aspects of safety and ecology. This is the only way we can ensure a sustainable and safe future for all participants in the transport system.

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Conflicts of Interest:

The authors declare that there are no conflicts of interest to disclose.

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