A Comprehensive Study of Effects of Renewable Energy Based Electric Vehicles on Environment

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***Abstract*—This extensive study explores the environmental impact of electric vehicles (EVs) powered by renewable energy sources. This review also looks at how they might lessen air pollution, cut carbon emissions, and support environmentally friendly transportation networks. Renewable energy-powered electric cars (EVs) have become a viable substitute for conventional internal combustion engine automobiles as the globe moves toward greener energy sources and looks for ways to tackle climate change. This essay examines how adopting EVs would affect the environment, with particular attention to resource use, air quality gains, and greenhouse gas emissions. It examines how EVs' life cycle emissions compare to those of conventional cars, taking into account things like how cars are made, how electricity is produced, and how end-of-life disposal is handled. The study also looks at how renewable energy sources like solar, wind, and hydropower can be integrated into the electrical grid to power electric vehicles (EVs), emphasizing the mutually beneficial effects on the energy and transportation sectors. The study also addresses the possible opportunities and problems that come with the widespread use of EVs powered by renewable energy, including infrastructural needs, legislative incentives, and customer behavior. This study aims to provide important insights into the environmental implications of EVs powered by renewable energy, guiding decision-making processes, and shaping future strategies for sustainable transportation and energy transitions through a thorough analysis of the body of existing literature, empirical studies, and modeling approaches.**

Keywords*—*Renewable Energy, Electric Vehicles, Environmental Impact, Challenges, Benefits

I. INTRODUCTION

Electric propulsion and renewable energy are two revolutionary technologies that come together to generate renewable energy-based electric vehicles (EVs). The main energy source for these cars is electricity, which is produced by renewable energy sources like solar, wind, hydroelectricity, and geothermal energy. Renewable energy-based electric cars (EVs) have various advantages over fossil fuel-powered traditional internal combustion engine vehicles, both environmentally and financially. Electric vehicles powered by renewable energy are a critical first step in building a more robust and sustainable transportation system that benefits society, the environment, and the economy [1]. These cars are positioned to be crucial in the shift to a low-carbon and sustainable future as renewable energy technologies develop more and EV adoption quicken. The transportation industry is experiencing a significant shift on a global scale as communities work to tackle urgent environmental issues, especially those pertaining to air pollution and climate change. Renewable energy-powered electric cars (EVs), which present a viable way to lower greenhouse gas emissions, enhance air quality, and encourage sustainable transportation, are leading this shift. Knowing the environmental effects of EVs powered by renewable energy is becoming more and more important as the need to decarbonize the transportation sector grows. With an emphasis on the contribution of renewable energy to EV power, this extensive study attempts to explore the complex environmental impacts of EV adoption [2]. This study aims to provide important insights into the environmental sustainability of EVs and inform decision-making processes aimed at accelerating their adoption and integration into transportation systems worldwide by analyzing the life cycle emissions, benefits to air quality, and resource implications of renewable energy based EVs [3].

Since the transportation industry contributes significantly to air pollution and carbon emissions worldwide, there is an urgent need to switch to greener, more sustainable options. The environmental effects of conventional internal combustion engine automobiles are being lessened by the use of electric vehicles (EVs). However, when an EV is fueled by renewable energy sources like solar, wind, or hydropower, its environmental advantages can be increased even more. In addition to lowering dependency on fossil fuels, this integration supports larger initiatives to decarbonize the energy industry and fight climate change. A thorough grasp of the environmental effects of renewable energy-based electric vehicles (EVs) across their whole lifecycle, from manufacture to disposal at the end of its useful life, is still necessary, despite the increased interest in and adoption of these vehicles. By carefully examining the environmental impacts of EVs powered by renewable energy, our study seeks to close this knowledge gap. This study looks at several environmental aspects, including resource use, air quality gains, and carbon emissions, in an effort to shed light on the possible advantages and disadvantages of a large-scale switch to renewable energy-powered electric vehicles [4]. The study will also investigate the prospects for expediting the shift to sustainable transportation systems by highlighting the synergies between the deployment of EVs and the integration of renewable energy. This study aims to educate policymakers, industry stakeholders, and the public on the role that EVs powered by renewable energy play in promoting environmental sustainability and influencing the direction of transportation using an integrated and multidisciplinary approach.

II. METHODOLOGY

The study starts with a comprehensive analysis of the body of knowledge already available on the subject, including scholarly research articles, reports from national and international organizations, industry publications, and other pertinent sources. An extensive grasp of the state of knowledge, important ideas, and research gaps pertaining to EVs powered by renewable energy sources and their effects on the environment is established by this study of the literature. The study gathers pertinent information on a range of topics related to EVs powered by renewable energy sources and their effects on the environment, such as carbon emissions, enhanced air quality, increased energy efficiency, and resource use. Numerous sources, including industry publications, government databases, academic research, and modeling simulations, may provide this data. After gathering the data, it is examined to find trends, patterns, and correlations as well as to calculate how much more environmentally friendly renewable energy based EVs are than conventional cars [5].

In order to examine the environmental effects of renewable energy-based EVs throughout the course of their whole life cycle—from raw material extraction and vehicle manufacture to use and end-of-life disposal—the study performs a life cycle assessment, or LCA [6]. To ensure consistency and comparability of results, this Life Cycle Assessment (LCA) uses standardized procedures and assessment tools to take into account several elements like energy consumption, greenhouse gas emissions, air pollutants, water usage, and land use.

The study uses modeling and simulation approaches to examine how EVs powered by renewable energy affect the environment in various situations and under various presumptions. This could entail estimating future trends in EV adoption and environmental sustainability, modeling the emissions and energy consumption of EVs powered by various renewable energy sources, and evaluating the effects of changes in technology, policy, and consumer behavior on environmental outcomes. Case studies of certain nations, areas, or communities that have adopted EVs powered by renewable energy sources or are thinking about doing so may also be included in the study. These case studies emphasize best practices, lessons learned, and opportunities for development by offering actual instances of the environmental advantages and difficulties related to EVs powered by renewable energy.

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A variation of cradle-to-grave, this scope focuses on the reuse of materials, aiming for a closed-loop system where products are either biodegradable or fully recyclable at the end of their life. Through surveys, seminars, focus groups, interviews, and surveys, legislators, business leaders, environmental organizations, and community members may be involved in the study. Their opinions and suggestions contribute to the design of the study, data gathering, analysis, and interpretation, and guarantee that the results are applicable, dependable, and practical. Through the use of a multidisciplinary approach that incorporates case studies, modeling and simulation, life cycle assessment, literature review, data collection and analysis, and stakeholder engagement, this extensive study seeks to offer a solid and fact-based examination of the environmental impacts of electric vehicles powered by renewable energy [7].

At several points throughout the LCA, important stakeholders will be contacted, including manufacturers, suppliers, end users, and sustainability specialists. These organizations provide a range of viewpoints that can be useful in spotting any biases or blind spots in the preliminary evaluation. Surveys, interviews, and focus groups will be used to collect feedback from stakeholders. This input will be thoroughly examined and incorporated into the phases of effect assessment, inventory analysis, and system boundaries. Based on the feedback, changes may be made to the impact categories, assumptions, and data sources.

III. RENEWABLE ENERGY

When we talk about renewable energy, we're talking about energy that comes from practically limitless natural sources that regenerate themselves over time. In order to produce energy or supply heating and cooling, these sources take advantage of natural processes or phenomena including sunshine, wind, water (hydroelectric), biomass, and geothermal heat. Because they emit few or no greenhouse gases, renewable energy sources are essential to the fight against climate change and air pollution. Renewable energy sources assist reduce reliance on finite resources and the environmental damage caused by fossil fuel extraction and combustion by dispensing with the need for fossil fuel-based energy sources [8]. Long-term sustainability is a feature of renewable energy sources, as opposed to the limited and non-renewable nature of fossil fuels. Renewable energy may be continuously extracted without running out as long as natural cycles such the ones caused by sunlight, wind, and water persist. By utilizing a wide range of renewable energy sources, the energy supply may be made more diverse and less dependent on any one source or geographic area for energy generation. By reducing susceptibilities to supply disruptions and price changes, this improves energy security [9]. The switch to renewable energy stimulates investment in developing sectors, innovation, and job development, all of which lead to economic opportunities. Jobs in a variety of industries are created by renewable energy technologies, which include wind turbines, biomass facilities, solar photovoltaics (PV), and manufacture, installation, and maintenance. Communities, regions, and countries can increase their energy independence and decrease their need on imported fossil fuels by utilizing locally accessible renewable resources. This can increase energy stability and

resilience, especially in regions that are susceptible to supply outages or geopolitical conflicts [10]. This paper focuses on various types of renewable energy resources viz. geothermal, wind, biomass, hydropower and solar shown in Fig. 1.

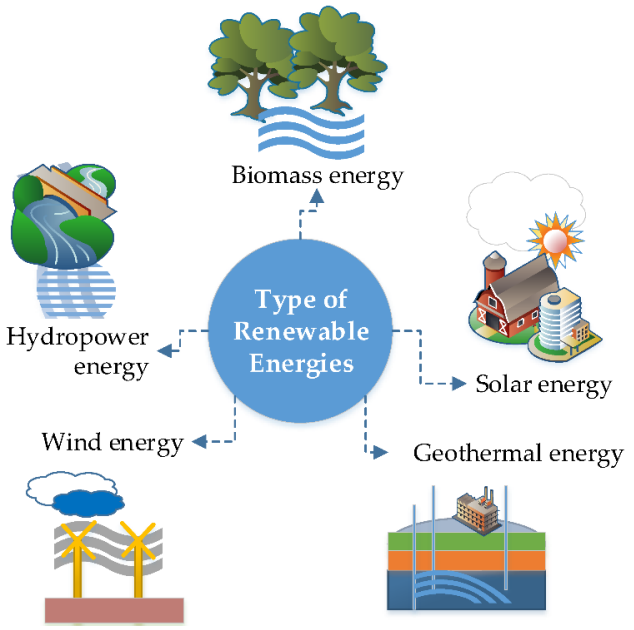

Fig. 1. The types of renewable energy resources discussed in this paper: biomass, solar, geothermal, wind, and hydropower [11]

Numerous renewable energy technologies facilitate decentralized and dispersed generation, including small-scale wind turbines and rooftop solar panels. This encourages energy self-sufficiency and lessens dependency on centralized power networks by enabling people, communities, and enterprises to produce their own clean energy. Renewable energy technologies are the subject of ongoing research and development, which propels technological improvements that increase efficiency, lower costs, and broaden the possible applications of renewable energy. Renewable energy systems are becoming more flexible and reliable due to developments in energy storage, smart grid technologies, and renewable energy integration. Growing the use of renewable energy is an essential part of the world's energy transition to a low-carbon, more sustainable energy system. The importance of switching to renewable energy in order to combat climate change.

IV. Renewable Energy Based Electric Vehicles

Electric propulsion and renewable energy generation are two sustainable technologies combined in renewable energy-based electric vehicles (EVs). Electric Propulsion: Rather of internal combustion engines (ICEs), electric motors power EVs. When these motors are operating, the car produces no tailpipe emissions because they are powered by an onboard battery pack. EVs contribute to a reduction in air pollution and greenhouse gas emissions related to mobility by doing away with the need for fossil fuels for propulsion. Electric propulsion and renewable energy generation are two sustainable technologies combined in renewable energy-based electric vehicles (EVs) [12]. Electric Propulsion: Rather of internal combustion engines (ICEs), electric motors power EVs. When these motors are operating, the car produces no tailpipe emissions because they are powered by an onboard battery pack. EVs contribute to a reduction in air pollution and greenhouse gas emissions related to mobility by doing away with the need for fossil fuels for propulsion. The electricity required to charge electric vehicle batteries can be produced using renewable energy sources like solar, wind, and hydroelectric power. The environmental advantages of electric vehicles (EVs) can be further amplified by including renewable energy sources into the infrastructure for charging them. By ensuring that the energy needed to power EVs originates from clean, sustainable sources, this strategy lessens the impact on the environment and reduces reliance on fossil fuels [13].

Solar-Powered Electric Vehicles: An EV's body or roof can be equipped with solar panels to generate electricity straight from the sun. Even though solar panels might not be enough on their own to fully charge an EV battery, they can increase driving range and lessen the demand for electricity from the grid. Applications like electric automobiles and buses are especially well-suited for solar-powered electric vehicles. Electricity generated by wind turbines and hydroelectric dams can be fed into the grid and utilized to charge electric vehicles. EV owners can lessen their carbon footprint and aid in the shift to a cleaner, more sustainable energy system by obtaining their electricity from renewable energy sources. To optimize the utilization of clean energy, EV charging infrastructure can also be placed strategically next to renewable energy projects. By storing extra electricity for later use, such as charging electric vehicles (EVs) during times of high demand or abundant renewable energy production, battery storage devices can supplement renewable energy generation. Smart grid technologies make it possible to control electricity supply and demand more effectively, maximizing the use of renewable energy sources and guaranteeing EV charging that is dependable. Wind and solar photovoltaic panels connecting electric vehicles to the grid shown in Fig. 2.

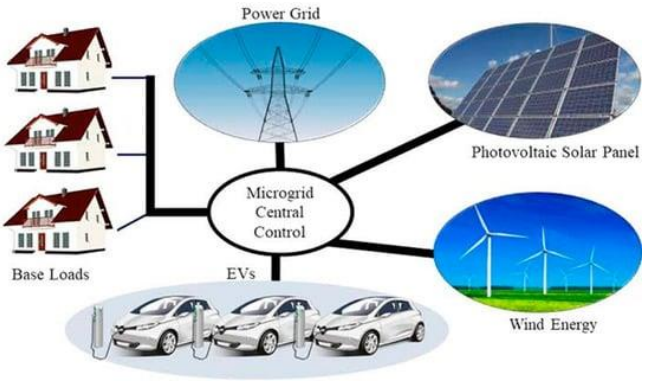

Fig. 2. Wind and solar photovoltaic panels connecting electric vehicles to the grid [14]

EVs powered by renewable energy have several advantages for the environment and the economy. They contribute to bettering public health and air quality by lowering greenhouse gas emissions and air pollution from transportation. They also support energy independence, the development of jobs, and the expansion of the renewable energy industry by using renewable energy sources. Government rules, subsidies, and incentives can hasten the adoption of EVs powered by renewable energy sources by lowering their cost and increasing their market appeal. To

increase the usage of EVs powered by renewable energy and meet more ambitious sustainability targets, policies that support the development of EV infrastructure, the deployment of renewable energy, and clean transportation are crucial. Electric vehicles powered by renewable energy provide an environmentally friendly mode of transportation that combines zero-emission car technology with clean energy production. We can lower greenhouse gas emissions, enhance air quality, and hasten the shift to a more robust and sustainable transportation system by using renewable energy sources to power EVs [15].

V. Effect of Renewable Energy Based Electric Vehicles on Environment

Electric vehicles (EVs) powered by renewable energy have a number of advantageous environmental consequences, chief among them being a reduction in air pollution, greenhouse gas emissions, and dependency on fossil fuels.

A. Lowering Emissions of Greenhouse Gases

The potential of electric vehicles (EVs) powered by renewable energy to lower greenhouse gas emissions is one of their biggest environmental advantages. Since electric motors rather than internal combustion engines power EVs, they operate with zero exhaust emissions. Combined with clean energy sources like hydroelectric, solar, or wind power, EVs can dramatically reduce transportation-related carbon emissions. Renewable energy-based EVs can slow down climate change and cut back on greenhouse gas emissions like carbon dioxide (CO2) and methane (CH4) by replacing fossil fuel-powered vehicles [16].

B. Enhancement of Air Quality

When an electric vehicle (EV) operates, it doesn't release any harmful pollutants like nitrogen oxides (NOx), particulate matter (PM), or volatile organic compounds (VOCs), like cars with internal combustion engines do. EVs can contribute to better air quality by switching to electric propulsion and renewable energy-based charging, especially in cities where car emissions are a major source of smog and air pollution. Cleaner air improves public health and quality of life by lowering the risk of respiratory ailments and other health issues linked to poor air quality [17].

C. Resource Conservation

By lowering the need for scarce fossil fuels like oil, coal, and natural gas, EVs powered by renewable energy help conserve resources. EVs reduce the environmental effects of the extraction, processing, and burning of fossil fuels and contribute to the conservation of non-renewable resources by producing electricity from renewable energy sources including sunshine, wind, and water. This encourages the sustainable use of natural resources and lessens the environmental damage brought on by the extraction and transportation of fossil fuels [18].

D. Minimization of Environmental Effects

Resource extraction, manufacturing emissions, and recycling at the end of life are just a few of the environmental effects that the production and disposal of EV batteries may have. However, the entire environmental impact of electric vehicles (EVs), including the production and recycling of batteries, is generally lower than that of conventional vehicles powered by internal combustion engines. This is especially true when charging the batteries using renewable energy sources. With time, more improvements in battery technology, recycling procedures, and sustainable materials can help EVs leave less of an environmental impact.

The demand for renewable energy generation infrastructure, such as solar panels, wind turbines, and hydroelectric dams, is driven by the development of EVs powered by renewable energy. Thus, funding for renewable energy projects is encouraged, hastening the shift to a clean, sustainable energy system. EVs assist local, regional, and global environmental sustainability, energy independence, and climate resilience by promoting the expansion of renewable energy.

VI. Challenges of Renewable Energy Based Electric Vehicles

In order for electric vehicles (EVs) powered by renewable energy to be widely adopted and integrated into the transportation system, a number of issues must be resolved.

A. Limited Driving Range

In comparison to conventional internal combustion engine vehicles, electric vehicles usually have a shorter driving range. Although EVs can now travel farther between charges thanks to advances in battery technology, some users are still concerned about range anxiety, or the possibility of running out of energy before arriving at their destination.

B. Infrastructure for Charging

Accessible and readily available infrastructure for charging electric vehicles is essential for their adoption. Nevertheless, establishing a thorough charging network necessitates a large investment in the construction of infrastructure, including workplace and public charging stations as well as residential charging options [19]. The absence of infrastructure for charging EVs continues to be an obstacle to their adoption in some areas.

C. Charging Time

Compared to refilling a regular car, charging an electric vehicle (EV) might take a lengthy time. Although they potentially shorten charging periods, fast-charging stations are not as common as conventional petrol stations just yet [20]. Long charging durations can cause annoyance to drivers and reduce the usefulness of EVs, especially when traveling large distances.

D. Cost of EVs and Batteries

Compared to traditional cars, the initial cost of electric vehicles (EVs) can be greater for models with larger batteries. Furthermore, a large chunk of the price of EVs is related to battery technology, and more developments in this area are required to lower costs and increase energy density. Even though a vehicle's lifetime savings on operating expenses might cover its initial cost, many buyers still struggle with upfront affordability [21].

E. Battery Life and Degradation

As EV batteries age, their performance and range are diminished. Battery longevity and life can be impacted by

variables like driving circumstances, charging habits, and temperature. To solve worries about battery deterioration and guarantee the long-term viability of EVs, it is imperative to improve battery durability and reliability.

F. Energy Storage and Grid Integration

Energy storage and grid integration face difficulties as EV adoption increases. Deploying EVs widely has the potential to strain the power grid and increase demand for electricity, especially during peak charging hours. To control the demand for EV charging and maximize grid stability, novel approaches are required, such as grid-balancing techniques, smart charging technologies, and vehicle-to-grid (V2G) technologies [22].

G. Resource Supply Chain

Limited global supplies of raw materials, including nickel, cobalt, and lithium, are needed for the production of EV batteries. In order to address concerns about resource scarcity, environmental consequences, and social responsibility, it is imperative to provide a sustainable and ethical supply chain for these materials, which includes responsible mining techniques and recycling activities.

H. Consumer Education and Awareness

Many customers still lack basic information on electric vehicles (EVs), including their features, technology, and infrastructure for charging them [23]. To boost public acceptance and adoption of EVs, it is essential to dispel myths, provide correct information, and raise awareness through outreach and education initiatives.

It will take cooperative efforts by stakeholders in the government, business, academia, and civil society to address these issues. To remove obstacles and quicken the shift to an electric car fleet powered by renewable energy sources and a cleaner, more sustainable transportation system, infrastructure investment, policy support, and customer involvement are crucial.

The shift to a more sustainable energy future is mostly driven by effective policy initiatives and cooperation amongst important stakeholders, including the government, business community, and consumers. Many countries have successfully implemented financial incentives to encourage EV adoption. For example, Norway offers generous tax breaks, exemptions from tolls, and reduced parking fees for EV owners. These incentives have made EVs more competitive with traditional vehicles, contributing to Norway's high EV adoption rates. Carbon pricing, such as the European Union's Emissions Trading System (ETS), imposes a cost on carbon emissions, encouraging companies to invest in cleaner technologies, including EVs. In the U.S., California's Low Carbon Fuel Standard (LCFS) incentivizes the use of cleaner fuels, further supporting the EV market and renewable energy integration.

VII. Benefits of Renewable Energy Based Electric Vehicles

A. Decreased Greenhouse Gas Emissions

When in operation, EVs emit no tailpipe emissions, which helps to mitigate climate change and reduce greenhouse gas emissions. EVs offer a totally emissions-free transportation option when fuelled by renewable energy sources like solar, wind, or hydroelectric power, further minimizing their environmental impact.

B. Better Air Quality

EVs contribute to better air quality, especially in urban areas where vehicle emissions are a major cause of smog and air pollution, by removing tailpipe emissions of pollutants like nitrogen oxides (NOx), particulate matter (PM), and volatile organic compounds (VOCs) [24]. The incidence of respiratory ailments and other health issues linked to poor air quality are decreased and public health is improved by cleaner air.

C. Energy Independence and Security

By reducing reliance on imported fossil fuels, renewable energy-based electric vehicles (EVs) improve energy independence and security. Using locally accessible renewable energy supplies, nations can lessen their dependency on foreign oil and lower the geopolitical risks involved in importing fossil fuels [25].

D. Energy Source Diversification

Electric vehicles (EVs) make it possible to include renewable energy sources like hydroelectric, solar, and wind power into the transportation sector [26]. This diversifies the energy mix and lessens dependency on fossil fuels. This promotes a more resilient and sustainable energy system, balances the supply and demand for energy, and increases energy resilience.

E. Cost Savings

Over the course of their lifetime, EVs will cost less to operate and maintain than cars with internal combustion engines [27]. Additionally, EVs fueled by renewable energy sources become more and more cost-competitive when compared to conventional vehicles driven by gasoline or diesel, as the cost of renewable energy continues to fall.

F. Employment and Economic Growth

The switch to EVs powered by renewable energy encourages investment, creativity, and the development of jobs in the renewable energy and electric vehicle sectors [28]. This encompasses the production, setup, use, and upkeep of EVs, as well as the infrastructure needed for charging them and the facilities needed to produce renewable energy, thereby fostering job creation and economic expansion.

G. Public Health Benefits

Electric vehicles (EVs) lower greenhouse gas emissions and air pollution, which improves quality of life and lowers healthcare expenditures [29]. Reduced rates of cardiovascular disease, respiratory ailments, and early mortality can result from cleaner air, which benefits people individually as well as in communities and society at large.

H. Technological Innovation

The advancement and development of renewable energy-based electric vehicles (EVs) propels advances in electric propulsion technologies, battery technology, and smart grid infrastructure. These developments support the development of clean energy sectors, advance technological advancements, and quicken the shift to a low-carbon, more sustainable transportation system [30].

Electric vehicles powered by renewable energy have several advantages for the environment, economy, and society. These advantages include lower greenhouse gas emissions, better air quality, increased energy security, cost savings, employment growth, advantages for the public's health, and technological innovation [31]. EVs are essential in accelerating the shift to a cleaner, more sustainable, and resilient energy future because they bring renewable energy sources into the transportation sector.

VIII. Discussion

This review's topic explores the complex effects of combining renewable energy sources with electric cars (EVs) and how this affects environmental sustainability. First off, the report emphasizes how much less greenhouse gas emissions are produced by EVs powered by renewable energy as compared to traditional internal combustion engine cars. EVs help to mitigate climate change and improve air quality by using clean electricity produced from renewable sources like solar, wind, and hydropower. This is especially important in urban areas where automobile emissions are a major concern. The discussion also looks at the increases in energy efficiency that come from combining EV technology with renewable energy sources. Internal combustion engines are less efficient than electric motors by nature, and electric vehicles (EVs) provide a more environmentally friendly and economical form of transportation when they run on renewable energy. This combination of EVs with renewable energy improves overall energy efficiency and lowers the transportation sector's carbon footprint.

Iceland has used its plentiful geothermal and hydroelectric resources to create exceptional energy resiliency. Its reliance on external energy imports is reduced because nearly all of its electricity is generated from renewable sources. Electric vehicles have also been encouraged by the government, as their growing use lessens the need for fossil fuels in transportation. Leading the way in combining renewable energy with the expanding EV industry is California. A more robust energy grid is a result of the state's significant investments in wind and solar energy. As part of a larger smart grid strategy, EVs are lowering emissions and balancing supply and demand thanks to programs like the California Public Utilities Commission's regulations.

The research also looks at how EVs powered by renewable energy might increase energy security and independence by varying the energy sources used for mobility. Countries can increase energy resilience and lessen their need on imported fossil fuels by utilizing an abundance of locally accessible renewable resources. The topic of discussion is how electric vehicles (EVs) powered by renewable energy are advancing technological advancement and market expansion. Transitioning to a cleaner and more sustainable transportation system is accelerated when renewable energy technologies are combined with electric vehicles (EVs) to promote breakthroughs in battery storage, charging infrastructure, and grid integration. These technological advancements generate new business opportunities and sectors in addition to enhancing the efficiency and affordability of EVs. The discussion also takes into account the difficulties and factors involved in the broad use of EVs powered by renewable energy. They include the requirement for a reliable infrastructure for charging, the difficulties in integrating the grid, the environmental effects of battery production and disposal over their whole lives, and the fair distribution of clean transportation options. Policymakers, industry stakeholders, and researchers must work together to create regulations that will help address these issues, invest in infrastructure, and increase consumer knowledge and adoption of EVs that run on renewable energy.

IX. Conclusion

The research also recognizes the obstacles and factors that need to be considered to fully utilize EVs powered by renewable energy sources. These include the requirement for strong charging infrastructure, legislation that are supportive, lifetime environmental assessments of battery production and disposal, and fair access to environmentally friendly transportation options. To overcome these obstacles, governments, business leaders, and academics must work together to create comprehensive plans that encourage the broad use of EVs powered by renewable energy sources while reducing adverse social and environmental effects. Electric vehicles (EVs) powered by renewable energy provide a revolutionary approach to building robust and sustainable transportation networks. Countries may move toward a low-carbon future, lessen their reliance on fossil fuels, and provide cleaner, healthier environments for present and future generations by utilizing renewable energy sources and electric propulsion. Global environmental sustainability can only be advanced and the promise of EVs powered by renewable energy must be fully realized via sustained research, innovation, and cooperation.

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