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An Overview of Influence of Hybridization in Automobiles on its Performance and Environment

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Abstract

The rapid advancements in transportation technology have led to the development of Hybrid Electric Vehicles (HEVs) and smart hybrid electric vehicles (S-HEVs) as potential solutions for reducing fuel consumption, emissions, and dependency on fossil fuels. These vehicles combine conventional internal combustion engine propulsion systems with electric propulsion systems, offering various driving modes and the ability to adjust operation points for increased efficiency. Additionally, HEVs and S-HEVs contribute to the creation of alternative power sources for household applications, provide ancillary services to the grid, and integrate intermittent resources for vehicle charging. The reliability of Electric Vehicle (EV) batteries is a crucial aspect, involving failure recognition, testing methods, and life prediction techniques to ensure prolonged battery life. As countries worldwide strive to transition from gasoline vehicles to EVs, practical limitations such as "range anxiety" due to inadequate charging infrastructure and high costs of long-ranged EVs arise. One potential solution to address range anxiety is the use of range extenders, optimizing driving range, costs, and vehicle performance. These advancements in eco-friendly, safer, and cost-effective transportation contribute significantly to reducing carbon emissions and promoting sustainable development globally.

Keywords: *Battery, Electric Motor (EM), Environment, Hybrid Electric Vehicle (HEV), Internal Combustion Engine (ICE)*

1.0 Introduction

Nicolas Otto's invention of the Internal Combustion Engine sparked a revolutionary transformation in the field of automobiles. Subsequently, petrol and diesel emerged as the primary sources of fuel for these vehicles. This technological breakthrough greatly facilitated human endeavours by becoming a widespread commercial commodity. As the 20th century progressed, numerous advancements were made to enhance the efficiency and affordability of this technology. Consequently, it achieved remarkable commercial success, leading to its widespread use in daily life. People can now traverse vast distances in a matter of hours, thanks to this revolutionary technology. However, like any innovation, it had both positive and negative implications. Unfortunately, at the onset of the 21st century, the levels of harmful pollutants such as Carbon Monoxide (CO) and Carbon Dioxide (CO_2) surged to dangerous levels, causing detrimental effects on the ecosystem, contributing to global warming, and triggering health-related issues. This alarming situation compelled scientists, researchers, and policymakers to prioritize and contemplate the development of green technologies that could mitigate the adverse impact on nature. Consequently, the 21st century has become an era of evolution in various technologies, with a particular emphasis on advancements in the automobile sector[1].

Several transformative technologies are set to revolutionize the automobile sector, including Hybrid Electric Vehicles, Hybrid Solar Vehicles, and

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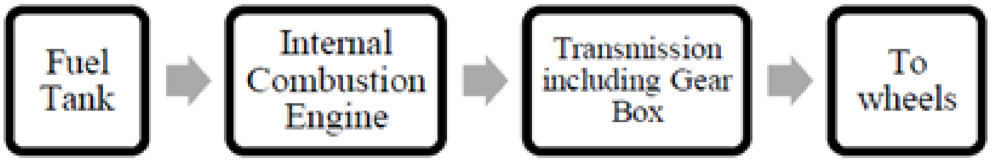

Figure 1. Flow of energy within a mechanical drive train[2].

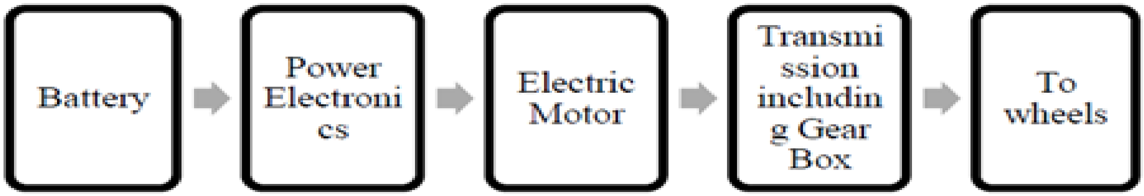

Figure 2. Flow of energy within an electric drive train[2].

Hydrogen Fuel Cells. An essential feature among these advancements is regenerative braking, a mechanism that efficiently converts the kinetic energy of a vehicle into another usable form, typically electrical energy. This energy can be utilized instantly or stored in high voltage batteries for future use, allowing for enhanced efficiency and sustainability in the automotive industry.

A hybrid electric vehicle is a unique type of vehicle that integrates both a traditional internal combustion engine system and an electric propulsion system (hybrid vehicle drivetrain). The purpose of incorporating an electric powertrain is to achieve either improved fuel efficiency compared to conventional vehicles or enhanced performance. The mechanical drive components encompass the fuel tank, which contains conventional fuels such as petrol, diesel, or Compressed Natural Gas (CNG), along with the combustion engine, gearbox, and transmission that deliver power to the wheels as shown in Figure 1. On the other hand, the electric drive system comprises the battery, an electric motor and power electronics responsible for control and management of the electric power as displayed in Figure 2.

The Smart Hybrid technology is a cutting-edge innovation designed to improve fuel efficiency and elevate the driving experience. With this technology, the engine intelligently shuts off when the vehicle is idle and smoothly restarts when optimal conditions are met, available in both manual and automatic transmissions[3]. Additionally, Smart Hybrid systems incorporate a dual battery setup, which includes a Lithium-Ion Battery, enabling enhanced performance and energy storage capabilities. Smart hybrid electric vehicles offer significant potential for reducing fuel consumption and pollutant emissions. These vehicles are equipped with multiple power sources, typically a combination of an internal combustion engine and an electric motor.

Smart hybrid electric vehicles feature various driving modes that adapt to different conditions. These modes include internal combustion engine driving alone, electric motor driving alone, internal combustion and electric motor driving together, and electric motor regenerative braking. This flexibility allows for precise adjustments to internal combustion engine's operation, ensuring optimal efficiency in high-performance areas. By integrating mechanical and electrical technologies, Smart hybrid electric vehicles can deliver outstanding performance in terms of dynamics, fuel efficiency, environmental sustainability, safety, and comfort.

2.0 Impacts of Hybrid Vehicles on Environment

The amount of CO_2 emitted from burning a gallon of fuel depends on the carbon content within the fuel. When fuel is burned, over 99% of the carbon present is released as CO_2. A small fraction is emitted as hydrocarbons and carbon monoxide, but these compounds quickly convert to CO_2 in the environment[4].

Table 1. Percentage of pollutant emissions from cars[6]

Vehicle Whole Life Carbon Emissions Analysis	Estimated lifecycle emissions (tonnes CO2e)	Proportion of emissions in production	Estimated emissions in production (tonnes CO2e)
Standard gasoline vehicle	24	23%	5.6
Hybrid vehicle	21	31%	6.5
Plug-in hybrid vehicle	19	35%	6.7
Battery electric vehicle	19	46%	8.8

'report prepared by Ricardo1for in collaboration with the Low Carbon Vehicle Partnership that includes major vehicle manufacturers and oil companies

To achieve cleaner and more sustainable transportation, electrification is considered the most effective approach[2]. Battery technology plays a crucial role in this endeavour. Currently, two prominent battery technologies are utilized in electric vehicles: nickel-metal hydride (NiMH) and lithium-ion (Li-ion). NiMH batteries are predominantly used in most hybrid electric vehicles available in the market due to their higher specific energy and energy density. However, the adoption of Li-ion batteries is expected to rapidly increase in plug-in hybrid electric vehicles and battery[5].

Given that 13 out of the top 20 polluted cities are in India, there is a pressing need for a substantial number of electric vehicles and hybrid electric vehicles in the country. The percentage of pollutant emissions from cars is presented in Table 1. This analysis considers the future scenario where non-renewable energy sources will become scarce, and nations such as India will rely heavily on renewable sources like wind and solar power to meet their energy requirements. With the anticipated growth in population, there will be an increased demand for transportation, making electric vehicles and hybrid electric vehicles the most suitable options to ensure cleaner and more sustainable integration of renewable energy.

With more regulation in the automobile industry to reduce these emissions, companies have responded by developing more efficient vehicles, i.e., Hybrid vehicles. Although doing so will not have a significant impact until all vehicles on the road are hybrid[6].

Most vehicles currently on the road emit harmful pollutants and waste, including nitrogen gas, carbon dioxide, and carbon monoxide. To address this issue, the automobile industry has been responding to increased regulations by developing more efficient vehicles, such as hybrids. However, the significant impact on the

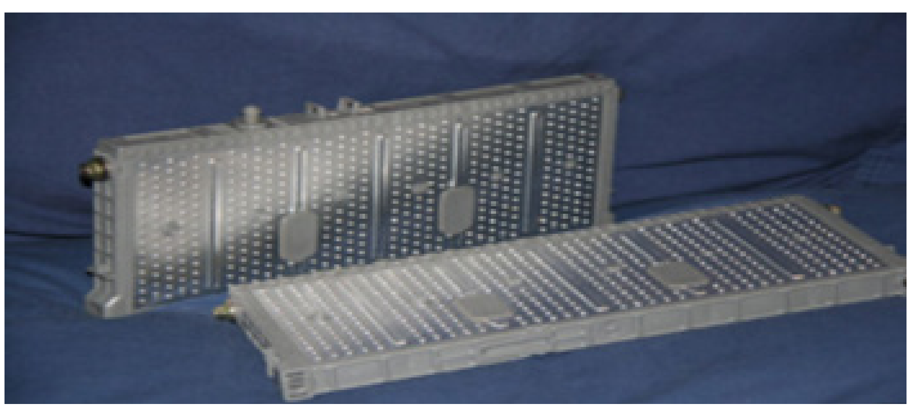

Figure 3. Nickel Metal Hydride Battery used in Hybrids[6].

environment will only be achieved when all vehicles on the road are hybrid.

Conventional vehicles powered by oil and gas impose a significant environmental burden by emitting chemicals, pollutants, and other waste materials. To address this issue, automobile manufacturers are turning to hybrid vehicles as a solution. Hybrid vehicles emit fewer and cleaner waste products, thereby contributing to lower pollution levels.

Hybrid vehicles utilize nickel metal hydride batteries, which, despite being less problematic than lead batteries, are more toxic. The toxicity of these batteries poses challenges for recycling and re-manufacturing processes, as companies strive to handle their disposal efficiently[7]. Additionally, many hybrid cars incorporate a combustion engine, which means that although they emit fewer emissions, a notable amount is still released into the environment. The electric engine in hybrids primarily operates at low speeds or when the vehicle is stopped, while the combustion engine takes over and emits similar waste as conventional vehicles when driving at high speeds. Surprisingly, plug-in hybrids running on electricity may unknowingly contribute to environmental harm. Depending on the source of electricity used for charging, if it comes from an oil or coal-dependent power grid, the environmental impact could be almost equivalent to that of someone driving a regular car.

Hybridizing Electric Vehicles brings about significant environmental consequences, encompassing both positive and negative aspects. Here are some key points to consider regarding the environmental impact of hybridization[8].

2.1 Fuel Consumption Reduction

Hybridization offers a primary advantage of decreased fuel consumption in comparison to conventional internal combustion engine vehicles. By combining an internal combustion engine with an electric motor, HEVs attain enhanced fuel efficiency, resulting in diminished Greenhouse Gas (GHG) emissions, including carbon dioxide and other pollutants. This contributes to a reduction in air pollution and mitigates global warming potential. The savings in fuel consumption of models in comparison with base models is displayed in Table 2.

2.2 Emission Reduction

HEVs emit fewer tailpipe emissions, particularly during urban driving conditions. The electric motor in HEVs can operate in zero-emission mode for short distances, effectively lowering local air pollution. Hybridization also enables the utilization of smaller, more efficient internal combustion engines that emit fewer pollutants when in operation[9].

2.3 Regenerative Braking

HEVs employ regenerative braking systems that convert kinetic energy into electricity, which is then used to charge the battery. By harnessing energy that would typically be

Table 2. Fuel Consumption savings of models under FAME scheme compared with base models

Technology	Hybrid/Electric Model (BEE Fuel Efficiency Star Rating)	Non-Hybrid/Non-Electric Base Model (BEE Fuel Efficiency Star Rating)	Gasoline Equivalent Fuel Consumption Reduction over Base Model
Diesel-Based Mild Hybrid	Maruti Ciaz VDI SHVS (5-Star)	Maruti Ciaz VDI (5-Star)	7%
Diesel-Based Mild Hybrid	Maruti Ertiga VDI SHVS (5-Star)	Maruti Ertiga VDI (4-Star)	15%
Gasoline-Based Strong Hybrid	Toyota Camry Hybrid (5-Star)	Toyota Camry AT 2.5 L (2-Star)	32%
Battery-Operated Electric	Mahindra E-Verito D2 (5-Star)	Mahindra Verito D2 (4-Star)	68%
Battery-Operated Electric	Mahindra e2o (5-Star)	–	–

dissipated as heat during braking, HEVs decrease energy loss and enhance overall efficiency.

2.4 Battery Production and Disposal

The environmental impact of hybridization is influenced by the manufacturing and disposal of the vehicle's battery. Battery production involves resource extraction, energy consumption, and emissions. Nevertheless, advancements in battery technology and recycling practices are mitigating the environmental impact of battery production and disposal[10].

2.5 Energy Source and Charging

The overall environmental impact of HEVs is contingent upon the energy sources employed for generating electricity and charging the vehicle's battery. Utilizing renewable energy sources like solar or wind maximizes the environmental benefits. However, if electricity primarily derives from fossil fuels, the indirect emissions associated with electricity production may partially offset the advantages of hybridization[11].

2.6 Lifecycle Assessment

A comprehensive lifecycle assessment is necessary to comprehensively evaluate the environmental impact of hybridization. This assessment should encompass factors such as vehicle production, operation, maintenance, and end-of-life disposal. It should also account for regional energy mixes to determine the complete extent of environmental benefits.

3.0 Consequences of Using Hybrid Electric Vehicles

3.1 Battery Production and Disposal

HEV batteries have environmental implications during production and disposal due to resource extraction, energy consumption, and emissions. To mitigate these issues, it is important to enhance battery manufacturing processes to minimize resource usage and emissions. Additionally, investing in recycling infrastructure and promoting the development of sustainable battery chemistry can maximize battery recycling rates.

The disposal and recycling of batteries were analysed by referring to environmental impact indicators found in scientific literature specifically related to lithium-ion batteries. Considering that different batteries have varying capacities and materials, a mass-based proportionality was used to adapt the available data to the batteries studied in this research. In this study, each battery cell was assumed to undergo pyro metallurgical recycling, a common method employed in Europe for recycling vehicle batteries. However, the pyro metallurgical process does not allow for the recovery of certain materials like graphite, plastic materials, aluminium, lithium, and manganese. These elements, particularly the last three, are retained in the slag generated during the process. The metal alloy and slag obtained from the pyro metallurgical process, which make up approximately 55% of the initial battery mass, undergo further refining through the hydrometallurgical process. This refining aims to recover the metal sulphates that can be reused in the production of cathodes for lithium-ion batteries[12].

3.2 Limited Electric Range

HEVs face limited electric range compared to plug-in hybrids and fully electric vehicles, resulting in increased reliance on internal combustion engines and higher fuel consumption. Addressing this challenge involves advancing battery technology to increase energy storage capacity, developing charging infrastructure to support plug-in hybrid options, and encouraging vehicle manufacturers to offer HEV models with extended electric range[13].

3.3 Dependence on Fossil Fuels

The dependence of HEVs on fossil fuels for internal combustion engines contributes to greenhouse gas emissions and air pollution. Transitioning to renewable energy sources for electricity generation is crucial to minimize the environmental impact of HEVs. By ensuring that the electricity used to charge HEV batteries is derived from renewable sources like solar, wind, or hydroelectric power, the environmental benefits of HEVs can be maximized[14].

3.4 Life Cycle Considerations

Considering the entire life cycle of HEVs is vital to comprehensively assess their environmental impact. This includes evaluating factors such as vehicle production, operation, maintenance, and end-of-life disposal. Implementing sustainable manufacturing practices, promoting responsible recycling of components, and reducing the use of environmentally harmful materials can help mitigate environmental concerns throughout the life cycle of HEV's[15,16].

3.4.1 Energy Grid Stress

As the number of HEVs increases, there may be added stress on the energy grid, especially during peak charging periods. This can strain existing infrastructure and potentially lead to greater reliance on fossil fuel-based electricity generation. Solutions involve optimizing charging infrastructure deployment, implementing smart charging systems prioritizing renewable energy sources and off-peak charging, and exploring Vehicle-to-Grid (V2G) technology that allows HEVs to supply power back to the grid during peak demand.

3.4.2 Environmental Impact of Rare Earth Metals

HEVs that use rare earth metals in their electric motors and other components can have negative environmental consequences due to mining and processing. Strategies to address this issue include developing alternative motor technologies that reduce reliance on rare earth metals, improving recycling methods for these materials, and exploring new sources of rare earth metals with lower environmental impact[17].

4.0 Solutions for the Said Consequences

The potential solutions to the challenges faced by HEVs as mentioned earlier is discussed below.

4.1 Battery Production and Disposal

Enhance battery manufacturing processes to minimize the consumption of resources and reduce emissions. This can involve optimizing production techniques and using more efficient materials. Invest in the development of robust recycling infrastructure to maximize battery recycling rates. This includes establishing collection systems and implementing efficient recycling technologies. Encourage the research and development of sustainable battery chemistries with reduced environmental impact. This entails exploring alternative materials and innovative designs that are eco-friendlier and more efficient.

4.2 Limited Electric Range

Foster advancements in battery technology to increase energy storage capacity and extend the electric range of hybrid vehicles. This involves investing in research and development to improve battery performance, energy density, and overall efficiency. Expand the charging infrastructure network to support plug-in hybrid options. This includes increasing the availability of charging stations, especially in urban areas, and providing convenient access to charging for HEV owners. Encourage automakers to prioritize the development of hybrid models with extended electric range, enabling drivers to rely more on electric power and reduce their reliance on the internal combustion engine.

4.3 Dependence on Fossil Fuels

Facilitate the transition to renewable energy sources for electricity generation. This involves promoting the use of clean energy from solar, wind, or hydroelectric power to charge HEV batteries. Governments can incentivize renewable energy adoption and support the development of renewable energy infrastructure. Encourage the use of renewable energy credits or certificates to ensure that the environmental benefits of HEVs are maximized. These mechanisms certify that the electricity used to charge HEV batteries comes from renewable sources, providing assurance to consumers and incentivizing the use of clean energy.

4.4 Life Cycle Considerations

Encourage automakers to adopt sustainable manufacturing practices. This includes using eco-friendly materials, implementing energy-efficient production processes, and reducing waste generation during vehicle manufacturing. Promote responsible disposal and recycling of components to minimize environmental impact at the end of the vehicle's life cycle. This involves establishing proper disposal channels and improving recycling technologies to efficiently recover valuable materials from retired HEVs.

4.5 Energy Grid Stress

Optimize the deployment of charging infrastructure to meet the growing demand for electricity during peak charging periods. This includes strategic placement of charging stations, load management systems, and infrastructure planning based on usage patterns and future projections. Implement smart charging systems that prioritize renewable energy sources and encourage off-peak charging. These systems can intelligently manage charging schedules to align with renewable energy generation and reduce the strain on the grid during periods of high demand. Explore innovative technologies such as Vehicle-to-Grid (V2G), which enables HEVs to supply power back to the grid during peak demand. V2G systems can help stabilize the grid by utilizing the energy stored in HEV batteries during periods of high electricity demand.

4.6 Environmental Impact of Rare Earth Metals

Support research and development efforts to develop alternative motor technologies that reduce or eliminate the reliance on rare earth metals. This involves exploring new motor designs, materials, and manufacturing techniques that can provide comparable performance without relying on scarce or environmentally harmful elements. Improve recycling methods for rare earth metals to ensure their safe and efficient reuse. This includes developing specialized recycling processes and establishing effective collection systems to recover rare earth metals from retired HEVs. Invest in the exploration of new sources of rare[18].

5.0 A Case Study (Toyota Prius)

The Toyota Prius as shown in Figure 4 holds the distinction of being the first hybrid car to be produced in mass quantities worldwide. In a report published in September 2019, Carmax ranked the Toyota Prius as the top choice among the 15 best hybrid cars. The Prius incorporates a 1.3 kWh battery that stores generated energy and provides an additional boost to the car when required. Unlike larger and more expensive battery packs, the Prius opts for a smaller and more affordable option. This design choice not only keeps the weight of the car down but also enables the battery to quickly regain power through regenerative braking[18].

Figure 4. Toyota Prius[18].

The Prius operates as a series-parallel hybrid, allowing it to turn off its 1.8L Internal Combustion (IC) engine and rely solely on the 53-kW electric motor, particularly at low speeds. In situations where the batteries are running low on power, and there is constant speed without braking, the engine remains on to power the vehicle and recharge the batteries. However, during full acceleration, the motor, and the engine work together simultaneously but with less power, providing a significant boost to the car's performance.

Under the hood of the Prius, both the engine and the motor are present, with the motor further divided into two separate motors: the first Motor Generator (MG1) and the second Motor Generator (MG2). MG1 serves as an initiation motor, connecting any additional power from the petrol engine to charge the batteries located under the backseat. On the other hand, MG2 functions as the main motor, powering the car during start up, re versing, and at low speeds. It also acts as a generator, capturing lost power when the brakes are applied. The Continuous Variable Transmission (CVT) of MG1 and MG2 ensures proper management of motor voltage levels. The Toyota Prius boasts an impressive fuel efficiency of 3.4 litters per 100 kilometres. The company claims that the battery design allows for charging and discharging over an extended period. As a result, the batteries come with a warranty that lasts up to eight years or a hundred and sixty thousand kilometres, providing peace of mind to Prius owners.

Therefore, the Toyota Prius, the first widely produced hybrid car, offers a combination of fuel efficiency, regenerative braking, and a compact yet powerful battery system. Its innovative design allows for seamless integration between the IC engine and the electric motor, providing a boost in performance while maintaining impressive fuel economy.

6.0 Conclusion

In conclusion, the hybridization of automobiles has a significant influence on both performance and the environment. Hybrid Vehicles (HEVs) offer improved fuel efficiency, reduced emissions, and enhanced driving experience compared to conventional internal combustion engine vehicles. The integration of electric motors and batteries in HEVs allows for regenerative braking, electric-only driving, and power assistance, leading to increased fuel economy and reduced greenhouse gas emissions.

However, the hybridization of automobiles also poses challenges that need to be addressed. Battery production and disposal limited electric range, dependence on fossil fuels for internal combustion engines, life cycle considerations, energy grid stress, and the environmental impact of rare earth metals are among the key challenges.

To overcome these challenges, various solutions have been proposed. These include enhancing battery manufacturing processes, investing in recycling infrastructure, advancing battery technology for longer electric range, promoting renewable energy sources for charging HEV's, adopting sustainable manufacturing practices, optimizing charging infrastructure deployment, implementing smart charging systems, exploring vehicle-to-grid technology, and developing alternative motor technologies with reduced reliance on rare earth metals.

By implementing these solutions and fostering collaboration among automakers, governments, research institutions, and consumers, the performance of hybrid vehicles can be further improved while minimizing their environmental impact. The ongoing development and adoption of hybridization technologies in automobiles contribute to a greener and more sustainable transportation future.

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