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# Carbon Emissions Life Cycle Assessment And Optimization Of Automobile Power System

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***Abstract***
*This entry relates to the assessment of environmental footprints between ICEVs and NEVS, more particularly life cycle carbon emissions and comparison as systems: it assesses life cycles of both systems from resource extraction and materials production through energy consumed in operation and finally post-life disposal with LCA methodology and GaBi software. Two components would be the focus of this study-the internal combustion engine for this conventional vehicle and the ternary lithium battery for the NEVs. Sensitivity analysis has shown that several factors would mainly affect total emissions, such as engine efficiency, battery types and selection, and materials. Worth mentioning is that the useful life of the batteries of electric vehicles was increased from 10 to 15 years to reduce emissions caused by manufacturing by between 10 and 15%, whereas an increase in energy density of battery by about 10% would lead to reduction of emissions as a result of production in the range of 5-10%. In addition, more than 85% reduction in charging emissions could be achieved as long as coal- fired electricity grids were converted into renewable ones.*
*Furthermore, it proposes optimization strategies intended to ameliorate the environmental impacts generated by automotive power systems. These include maximized energy efficiency for onboard systems, low-carbon materials, and advanced battery technology for higher energy density, recyclability and longer lifespan. The quantitative estimates state that if, in 2030, 30% of the world's fleet were converted to electricity, that could save between 1.5 million metric tons of $CO_2$ each year. Even beyond this, possibly, emissions during production could see a 30% to 40% benefit from continued technological advances such as solid-state batteries and second-life applications for used batteries. Thus, the great potential of NEVs is conditioned by the greenness of the electricity they consume especially during their operation. The implementation of renewable energy and the construction of cleaner fuels (biofuels and synthetic alternatives) may also account for 20-40% reduction in non-electric sectors.*
*In short, the thesis posits that sustainable vehicle technologies are vital for reducing carbon emissions in transportation. Regulatory drivers, partnership among industries, and technological advances may provide a route for decarbonizing the sector. This ultimately calls for further investigations into the optimization of vehicle power systems toward achieving performance, cost, and environmental impact especially regarding renewable energy integration and battery recycling.*

***Keywords:*** *Life Cycle Assessment (LCA), Carbon Emissions, Automotive Power Systems, Environmental Impact, Sustainability Optimization.*

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## I. Introduction

This foundational chapter, apart from giving background information, describes the current research landscape, the significance, and the scope of work. It begins with the growing worldwide concern of carbon emissions and environmental sustainability, particularly that of transport, which is one of the major greenhouse gas contributors. Following this, the review of the present state of research pertaining to carbon emission reductions emanating out of automotive power systems identifies the need for a full life cycle assessment covering environmental impacts beyond the use phase. Thus, the unique contribution of the present study can be considered a comparison of carbon reduction pathways of conventional internal combustion engine vehicles versus new energy vehicle power systems. All of these lead to a discussion of the research objectives, questions, and structure of the thesis, all of which prepare the reader for the in-depth analysis in the stated following chapters.

**Research Background:**

Rapidly rising greenhouse gas emissions from the transport sector, which accounts for about 25% of $CO_2$ emissions worldwide, have worsened the global climate crisis. Road transport having been one of the greatest contributors to the climate has made it necessary to fight against the consequences brought about by vehicles. Life Cycle Assessment (LCA) has now gained acceptance in evaluating the total environmental impact of automotive power systems, such as internal combustion engine vehicles (ICEVs), hybrid electric vehicles (HEVs), battery electric vehicles (BEVs), and hydrogen fuel cell vehicles (HFCVs). Traditionally, research was focused on improving ICE efficiency, but now stricter regulations demand alternative source power technologies, electric and hydrogen technology sources. Still, LCA could be helpful in determining the real environmental worth—emissions from production to disposal.

**Importance of Optimization of Automotive Power Systems:**

Efforts to achieve carbon neutrality and avert climate change on an international scale impacted life cycle assessment (LCA) methods for the design and optimization of automotive power systems. It offers an understanding of the phase of the vehicle life cycle that contributes to the greatest carbon emission mitigation, hence assisting the designer in creating cleaner-fast- efficient-mobility solutions. In consideration of carbon taxes, emissions trading systems, and incentives to encourage clean energy, government policies are becoming increasingly important in shaping local automobile manufacturing strategies. Internal combustion engine improvements had been at the forefront, but more and more focus was placed on developing electric and hydrogen vehicles with the tightening of regulations with regard to emissions. However, their complete environmental burden that includes battery production, energy sources for electrical power, and vehicle disposal must be analyzed by LCA.

**Research Significance:**

This study is meaningful because of the specific urgent environmental issues created by the motor vehicle industry, which is one of the greatest sources of greenhouse gas emissions globally. Under the progressive moves of nations toward carbon neutrality in agreements such as the Paris Agreement, it becomes a necessity for automakers to implement sustainable technologies and strategies. It seeks scientific evaluation through Life Cycle Assessment (LCA) of different vehicle power systems designed to give informed knowledge to support eco-design and global best practices. Internal combustion engine vehicles dominate the manner of transport but also contribute harmful pollutants that increase climate change and health problems, as cities continue to develop and demand for vehicles increases.

Cleaning technologies as electric, hybrid, and hydrogen fuel cell vehicles are now an environmental and economic necessity. The innovations are not free, though, as they need huge investments, R&D, battery improvements, infrastructure (charging stations), and an optimally working supply chain: production to disposal. For closing knowledge gaps in vehicle technology, energy storage, and recycling, the sustainable mobility becomes achieved. Certainly, policy support through incentives, stricter standards, and carbon pricing would be vital to hasten this transformation.

Relevant studies which continue to grow and develop ignore the long life cycle impacts of these technologies, concentrating only on a particular stage such as during usage or production. This research aims to fill that gap by offering a detailed perspective on LCA issues up to the extent of assessing environmental impacts from raw material extraction up to end-of-life recycling. Moreover, it will quantify the complete carbon footprint of various powertrain technologies as well as uncover hidden environmental costs. The results will thereby provide a source to drive policy decisions, manufacturing improvement, and ultimately a transition towards a low-carbon future for the automotive sector.

## II. Evaluation Methods

**Introduction to Life Cycle Assessment**

Life cycle Assessment (LCA) is a systematic and quantitative analytical tool used to determine the environmental consequences of all stages of a product's life cycle. Therefore, the assessments give a wholesome angle to the environmental burdens concerning raw material extraction, material processing, manufacture and distribution, use and maintenance, and final disposal or recycling. Consequently, LCA is built to be applicable for understanding the entirety of the life cycle in which the environmental, sustainability-wise insight includes resource consumption, energy use, emissions, and waste generation.

LCA has also been well-acknowledged for its contribution toward informed decision- making in industries where the aim is to minimize ecological footprint. Another major application of LCA is to act as an important toolkit for sustainable product/process innovation while identifying key intervention points for reducing environmental impacts. In comparison, companies and researchers would be optimizing materials, energy efficiency, and waste management strategies to maximize sustainability while assuring the functional performance of a product and its economic viability. This path works in unison with global sustainability goals and legal frameworks that strongly promote environmentally sound manufacturing and product development.

**Methodology and Structure**

Life Cycle Assessment (LCA) is a stepwise and methodical approach that allows for comprehensive evaluation of environmental impacts brought about by a product, process, or service. The method seeks to offer a methodical and scientifically valid appraisal so that it is a widely accepted instrument for sustainability evaluation. LCA has four key stages, each with a key contribution towards ensuring the attainment of accurate and meaningful results

**Unit Process Data Collection:**

It goes without saying that sound LCA for carbon footprint requires the collection of accurate and complete information through the life span of a vehicle. There are three broad categories of data: (1) production, which considers emissions from producing vehicle components such as internal combustion engines, electric motors, and batteries, mainly pertaining to material and energy use; (2) use, which includes emissions from driving and fuel or electricity consumption as well as maintenance activities and replacement of parts; and (3) disposal, which looks at the environmental effects of the dismantling, recycling, and disposal of the vehicle, especially those due to metals and batteries. All these data give an assessment and comparison to environmental impacts on different power systems (ICE, HEV, BEV) and help in the strategy of emission reduction and sustainable vehicle design.

## III. Modeling And Data Collection

**LCA Software Operation**

GaBi (Ganzheitliche Bilanzierung) is reputed as the most in-demand LCA modeling computer software tool worldwide for environmental impact modeling of a product life cycle. GaBi was developed by Sphera (formerly thinkstep), as a holistic tool used for simulating material, process, and energy flows to ultimately measure and reduce carbon emissions. The system allows for highly complex models of automotive drive systems with inputs into the raw material extraction, manufacturing, use, and end-of-life processes.

Perhaps the strongest argument in support of GaBi is its huge database and data varies in emissions, drivers of energy consumption, and material flows from many different industries. This means environmental impact can be calculated to the nth degree for ICE vehicles, BEVs, as well as hybrid powertrains. In this way, GaBi allows the exploration of what-if scenarios for changes in fuel efficiency or battery chemistry, following up with the testing of the resulting impacts on carbon emissions.

GaBi operates in a modular fashion, allowing users to modify unit processes, link them with relevant environmental data, and carry out impact assessments in accordance with standardized procedures such as ISO 14040/14044. Also, GaBi enables sensitivity analysis to investigate the impact of different input parameters on LCA results. This feature also helps in optimization for vehicle power system analysis, identifying potential emission reduction areas.

Additionally, interconnecting with external databases like Ecoinvent and GREET increases the reliability of GaBi by maintaining an alignment with the industry standards and regulatory framework. It enhances its use for visualization by providing graphical tools for interpreting results and communicating the findings.

**GaBi Workflow for Automotive Power Systems**

Using GaBi, to guarantee a systematic and dependable Life Cycle Assessment (LCA), a four-fold approach is adopted: goal and scope, life cycle inventory (LCI) construction, life cycle impact assessment (LCIA), and design optimization with solution options.Result Interpretation and Design.

Step 1: Setting the Goal and Scope in GaBi

With the first step of the LCA study, the functional unit is defined to enable proper comparisons between the different technical options for the vehicle powertrains (e.g., emissions per square kilometer of traveled distance or lifetime of the vehicle). After that, the next stage is demarcating the boundaries of the system; that is, whether it should follow the cradle-to-grave option (which covers the full life cycle) or cradle-to-gate (cutting off at the manufacturing phase). The impact categories that are to be inspected- carbon footprint, energy consumption, and those that could deplete our resources- are going to be selected. Any regional differences along the lines of electricity grids would need to be modeled since they affect the environmental impacts associated with Battery Electric Vehicles (BEVs) maintenance).

Step2: Construction of the Life Cycle Inventory (LCI)

All relevant material and energy inputs are finally compiled now. Data on material consumption currently includes extraction and processing of lithium for EV batteries and steel for vehicle chassis in the extensive GaBi database. Process modeling involves assigning manufacturing processes, transportation, and energy flows to different stages of the life cycle. In order that emissions outputs are correctly represented within the system. Such are the GaBi conditions so that no amounts fail to come for life-cycle assessments. Emission factors from regulatory databases and scientific sources are then integrated into GaBi so that it is now possible to quantify environmental impact accurately.

Step 3: LCIA Implementation

GaBi possesses its built-in impact assessment method such as CML, ReCiPe, and IPCC, which can be used to evaluate the emissions by various environmental categories. Global Warming Potential (GWP) values of IPCC are employed in calculating $CO_2$-equivalent emissions, which takes into account an accurate perspective in analyzing the impact on climate. The software allows for comparison possibilities among the differences in powertrain technologies and trade-off emission scenarios possible for internal combustion engine vehicles (ICEVs), hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and battery electric vehicles (BEVs).

Step 4: Interpretation and Optimization

At this ultimate level, analyzing the output data will help in identifying key emission hotspot areas. For instance, in the case of BEVs, GaBi would point out battery production as having a high carbon footprint, an area that would then be targeted for improvement in sustainability strategies. Sensitivity analysis will be applied to determine the effect of changes in the energy mix on the emission results. Lastly, optimization would involve strategies related to material selection and energy supply to minimize the total carbon footprint of automotive power systems.

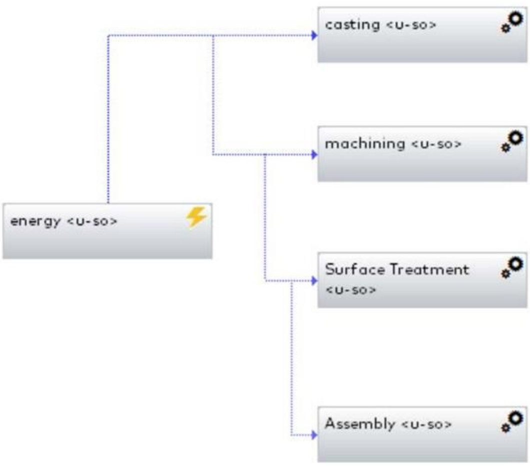


**Figure 1: GaBi modeling for energy consumption**

**Table 1: Energy Consumption and Emissions by Manufacturing Process**

| Process | Energy Consumption (MJ/unit) | Emission Factor (kg $CO_2$/unit) |
|---|---|---|
| Casting | 500 – 700 | 50 – 70 |
| Machining | 100 – 200 | 10 – 20 |
| Surface Treatment | 50 – 100 | 5 – 10 |
| Assembly | 30 – 50 | 3 – 6 |

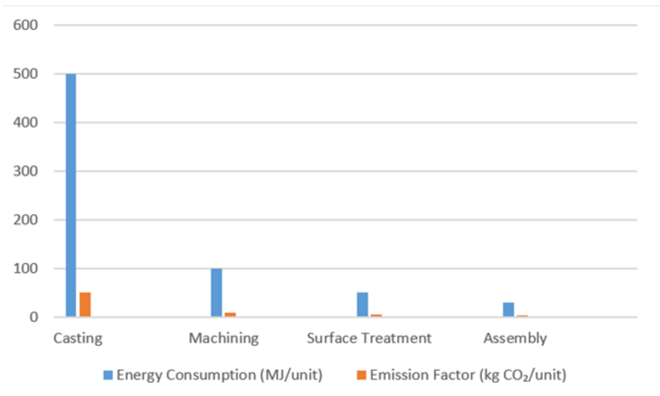


**Figure 2: Energy consumption and emissions by manufacturing process**

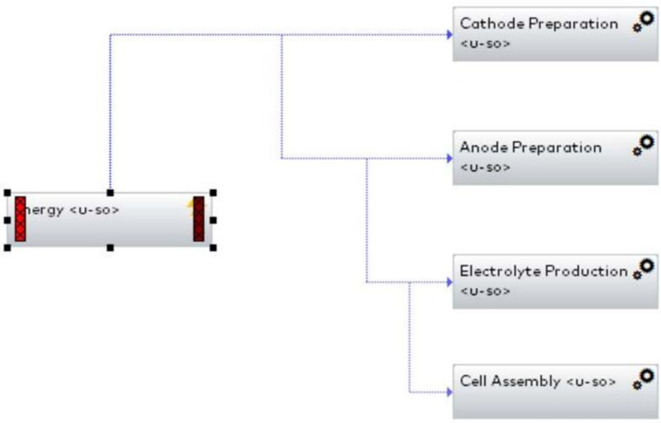


**Figure 3: Modeling of battery manufacturing processes**

**Table 2: Energy Consumption and $CO_2$ Emissions in Battery Manufacturing Processes**

| Process | Energy Consumption (MJ/kWh) | $CO_2$ Emissions (kg $CO_2$/kWh) |
|---|---|---|
| Cathode Preparation | 500 – 700 | 40 – 60 |
| Anode Preparation | 300 – 500 | 20 – 40 |
| Electrolyte Production | 100 – 200 | 10 – 15 |
| Cell Assembly | 200 – 400 | 15 – 30 |

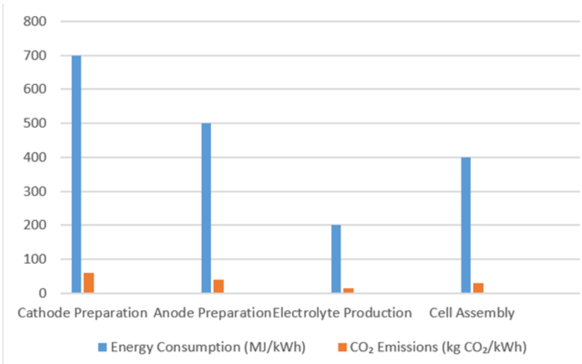


**Figure 4: Modeling results of battery manufacturing processes**

**Table 3: Carbon Footprint Breakdown by Lifecycle Phase**

| Lifecycle Phase | ICEV Emissions (tons $CO_2$) | BEV Emissions (tons $CO_2$) | Notes |
|---|---|---|---|
| Manufacturing | 5–10 tons | 8–12 tons | BEVs have higher emissions due to battery production. |
| Use Phase | 40–50 tons | 10–20 tons | BEVs have lower emissions, depending on the electricity grid. |
| End-of-Life Recycling | 1–2 tons | 1–2 tons | Recycling batteries can reduce BEV emissions further. |
| Total Lifecycle | 50–60 tons | 20–30 tons | BEVs have a lower total carbon footprint over their lifetime. |

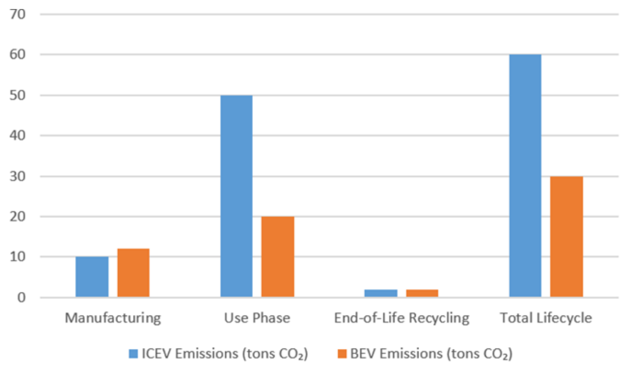


**Figure 5: Carbon footprint of BEV AND ICEV**

**Evaluation And Comparison Of LCA Results**

These findings span a large variety of categories when it comes to the environmental impact, including carbon footprint, energy consumption, resource utilization, and water usage. The comparison involves standard internal combustion engine vehicles (ICEVs), owned combustion-engine vehicles, and newly invented energy vehicles (NEVs), where battery electric vehicles (BEVs) are highlighted as a better environment in which to operate. This chapter provides a comprehensive and thorough comparison after extensive data collection and carefully defined assumptions concerning the model by analyzing these issues from various perspectives.

The evaluation tells the reader what differences exist in emissions across various vehicle types taking production, operation, and end-of-life phases into consideration. Overall, greenhouse gas emissions are commonly higher in traditional ICEVs, as opposed to NEVs which show lower carbon emissions especially with battery electric vehicles since they use electricity power. However, the environment-lowering effects of NEV depend on the energy generation methods since regions with high dependence on coal production can still end up with being major polluters. There is also a variation in resource consumption as most of the critical materials like lithium, cobalt, and nickel are utilized for the manufacture of batteries in BEVs, bringing resource depletion issues and environmental concerns regarding mining.

Water is also an important variable in the context of vehicle manufacturing and energy production. Although BEVs tend to be low-emission during their use phase, most of the battery production lightens the water for the process and must be included in all sustainability analyses. This chapter will thus provide a complete picture of the environmental trade-offs of different propulsion technologies and will enhance the discussions around sustainable strategies in transport. The study will also make a thorough value comparison of these elements to help optimize vehicle design, energy sourcing, and recycling strategies for a reduced overall impact of the automotive system on the environment.

Carbon Footprint Comparison

At the center of most life cycle assessment (LCA) measurements is the carbon footprint, i.e., the operation production and end-of-life stage greenhouse gas emissions (GHGs) associated with the life cycle of a vehicle. The carbon footprint of internal combustion engine vehicles (ICEVs) happens mainly in the operation stage due to fuel combustion utilized. LCA analysis indicates that ICEVs emit a lot of emissions per unit of distance, if they are powered by fossil fuels, which emit carbon dioxide into the air. Room emissions during production, engine; transmission system; and chassis material emissions are significant, although generally much less than electric vehicle (EV) battery production, in terms of carbon emissions. On the road, ICEVs emit 150-200 g of $CO_2$ per kilometer depending on the fuel and vehicle type. BEVs lack tailpipe emissions but their total carbon impact is determined by the energy-hungry process of making batteries, involving the mining and processing of raw materials like lithium, cobalt, and nickel. BEV manufacturing emissions, under the disguise of battery manufacturing emissions, could account for 50-70% of the vehicle's total life cycle emissions. Even though BEVs emit zero carbon on the road, they have a carbon footprint related to the grid which they are being charged. If the grid is dominated by fossil fuel, then the carbon footprint of BEVs could be higher but lower than ICEV. Therefore, while BEV has a dramatic edge in the region of tailpipe emissions, its net environmental effect depends on the manufacturing process and on the charging energy source.

## IV. Sensitivity Analysis And Optimization

**Engine Sensitivity Analysis**

In this section, i perform a sensitivity analysis to understand how various parameters influence carbon emissions associated with conventional Internal Combustion Engine Vehicles (ICEVs). Sensitivity analysis is the prime tool that looks at how some specific relevant factors and variables affect the overall environmental footprint, in this case, the carbon emissions of the engine through its life cycle. By varying different parameters in this analysis, we want to look at the most relevant contributors toward emission and see if some measures can then be put in effect to curb the carbon footprint. One of the major aspects of this analysis is studying how variation in fuel consumption leads to emissions. Burning less fuel while operating the vehicle equals lesser carbon emissions. Thus, the link between fuel efficiency and emissions needed to be understood well. Design improvements at the engine level or alternative fuels could result in a much-decreased level of carbon emissions, while also another measure like optimized driving, for example, lowering the air speed or avoiding sudden acceleration of the vehicle, would save on fuel and diminish emissions as well.

Apart from fuel consumption, engine efficiency on emissions is also analyzed. The efficiency of an ICE engine is an indicator of its performance regarding converting fuel into useful energy. Engines classified as high-efficiency use less fuel for an equal level of performance and, thus, less greenhouse gas as a function of their lifetime. Various engine parameters, accordingly, will affect engine performance and hence carbon emissions, e.g. compression ratio, turbo or supercharging, and exhaust gas recirculation (EGR).

The analysis considers another factor: vehicle weight, which directly affects its overall energy demand in operation. Lighter vehicles generally consume less fuel as lesser energy is required to pour the weight around. Hence, weight reduction on a vehicle by using lighter materials such as aluminum instead of steel will thus lead to less emissions in the operational phase.

Lastly, engine maintenance and age form other major variables in the analysis. Old engines are generally less efficient, due to wear and tear, resulting in greater fuel use and, thus, higher emissions. Regular maintenance followed by the replacement of old engines with newer engine technologies would help in great measure to reduce carbon emissions from conventional engines.

Overall, an understanding of causes and effects of emissions characterized by the sensitivity analysis provides very insightful findings regarding the factors which change emissions greatly and the mechanisms of how those factors can be adjusted to reduce the environmental impact given ICEVs. Value from improved technologies that enhance fuel efficiency and reduce emissions become evident when consideration is given to engine performance and vehicle weight concerning emission factors.

**Table 4: Sensitivity Analysis Parameters for Automotive Power Systems**

| Parameter | Test Range | Baseline Value | Data Source |
|---|---|---|---|
| Fuel Consumption | ±25% of baseline | 6.8 L/100km | EPA Fleet Testing Database |
| Engine Efficiency | 18% to 35% | 28% | SAE J1349 Certified Data |
| Material GWP | 2.1-8.5 kg $CO_2$/kg | 4.3 kg $CO_2$/kg | Ecoinvent v3.8 LCA Database |
| Operational Load | 30% to 100% of maximum | 70% | NREL Vehicle Testing |
| Maintenance State | New to 200,000 km | 100,000 km | AECC Long-Term Durability Study |

**Sensitivity analysis of ternary lithium batteries**

Power supply charging is identified to have the greatest influence on carbon emissions in the life cycle of ternary lithium batteries, according to sensitivity analysis. The source of energy utilized for charging exerts considerable long-term influence on total emissions of electric vehicles. It was found that if the charging grid is carbon-based, emissions are almost three times higher compared to instances where renewable energy sources like wind or sunlight dominate the grid. Thus, this finding emphasizes the imperative need for greening energy integration so that electric vehicles can offer maximum environmental benefits. The move to clean sources of power will drastically bring down the carbon emissions of electric vehicle batteries, making them potentially a truly sustainable substitute for conventional internal combustion vehicles. The next most crucial factor of life cycle emissions would be mining and processing raw materials, where nickel and cobalt mining would account for considerable emissions.

These metals as cathode materials for ternary lithium batteries are linked to energy-thirsty extraction and refining processes that in turn generate humongous environmental degradation. Material utilization optimizations, improved extraction processes, and recycling can alleviate this to some extent. Improved recycling technology and some alternative material development to other battery chemistries can also alleviate ash emissions and maintain performance. Another important determinant of the overall emissions is the battery life and rate of degradation. Research indicates that an increase in battery life by 20% would lower overall emissions by approximately 15%.

More durable batteries are being replaced less frequently than their cut-off counterparts, thus saving on demand for new material and minimizing the environmental footprint of manufacture and disposal. Therefore, development in battery life and resultant degradation-resistance chemistries is further essential to sustainable enhancement. Development of solid- state batteries and high-cycle-life electrolytes will go a long way towards achieving these goals. Whereas manufacturing efficiencies are propelling emissions, its contribution is negligible against the above-sited factors. Certainly, the use of renewable energy sources like solar and wind to power battery manufacturing units would go a long way in ensuring the entire lifecycle of the battery supply chain is maximally sustainable. A power sourcing change in manufacturing would also lower emissions, hence making decarbonizing industrial energy consumption pivotal to sustainable battery supply chain evolution.

**Table 5: Emission Sensitivity Comparison**

| Parameter | Change Applied | Impact on Life Cycle Emissions – ICE (%) | Impact on Life Cycle Emissions – Battery (%) |
|---|---|---|---|
| Fuel Efficiency / Battery Efficiency | +10% increase | −8.2% | −5.6% |
| Fuel Type / Charging Energy Source | Switch to low-carbon alternative | −22.5% | −34.7% |
| Material Extraction and Processing Emissions | Use of cleaner production technologies | −6.1% | −13.4% |
| Component Recycling Rate | +20% increase | −2.5% | −9.7% |
| Component Lifespan | +20% increase | −4.3% | −11.2% |

## V. Conclusions

A thorough examination of the life cycle assessment (LCA) about automobile power systems has been completed by the study, wherein it examined the environment importance of both vehicles with internal combustion engines (ICEs) as well as new energy vehicles (NEVs), integrating ternary lithium battery systems. This assessment encompassed all the stages of the vehicle life cycle, including raw materials extraction, manufacturing, and end-of-life disposal. The results obtained by the study indicated that greenhouse gas emissions by ICE vehicles have their origins largely in the combustion of fossil fuels to meet energy requirements during operation. Moreover, production and disposal phases, especially recycling, are extremely resource-intensive. In contrast, NEVs suffer from very high environmental burdens during the production of ternary lithium batteries, and particularly arising from extraction and processing of some critical materials like lithium, nickel, and cobalt. Finally, the carbon footprint of NEVs is also strongly defined by the type of electricity, used during battery production and vehicle charging and thus the energy mix is a significant variable in overall environmental performance.

The research identified crucial aspects that change mobilizing extent in environmental aspects both for ICE and NEV systems through sensitivity analysis. Fuel-saving strategies and hybrid technology in conjunction with ICE operate with electric powertrains providing effective avenues for reduction of fossil fuel use and emissions in conventional engines. NEV can reduce emissions associated with vehicle operation and battery charging by raising renewable energy into the share of the electricity grid. It has also been known that extending the life of batteries and improving recycling technologies is important for reducing material extraction needs, therefore, reducing the environmental problems created by battery production. All of this implies that targeted optimizations in energy sources, new technologies in battery systems, and sustainable production methods can increase the sustainability of traditional and electric vehicles in their life cycles.

This primarily signifies when numerical projections are made whether optimization strategies exist at diversified levels for reducing carbon emissions. Future projections, however, indicate that up to 30-50% reduction can be achieved in lifetime emissions by 2050 when old internal combustion engine vehicles are replaced much gradually by new electric vehicle technologies utilizing comparatively cleaner energy. But it actually depends on how fast the market spin offs around such technologies and on energy mix in specific regions. For example, if 30% of the global fleet was made electric in 2030, it would mean an annual global reduction of about 1.5 billion metric tons of CO2 emissions across the entire transport sector. Changes in battery lifetime used in electric vehicles to 10-15 years may yield a reduction of approximately 10 to 15% in emissions produced during their manufacture while a 10% increase in energy density of batteries may incur savings in production emissions of about 5 to 10%. Furthermore, if electricity grids EVA which is used to charge electric vehicles were to shift from coal-based ones, emitting around 0.9 kg CO2/kWh, to renewable dominated ones of below 0.05 kg CO2/kWh, the emissions from charging could be reduced by up to 85%. All this indicates why renewable energy integration, battery technologies and smart policy interventions are crucial in advancing low carbon transportation systems.

There are different optimization strategies available at different levels of reducing carbon emissions, as it is numerically projected. Future projection, however, shows that lifecycle emissions can be reduced by as much as 30-50% by the year 2050 if all old internal combustion engine vehicles are gradually replaced with upcoming electric vehicle technologies harnessing relatively cleaner energy. This, however, depends on how fast the market spins off around those technologies and the energy mix in specific regions. For example, assuming that by 2030, 30% of vehicles globally would be electric, then such condition would mean an annual reduction of around 1.5 billion metric tons of CO2 emissions from the entire transport sector. Changes in useful life of batteries used in electric vehicles from 10-15 years may yield about 10-15% reduction in emissions incurred during their manufacturing phase, whilst a 10% increase in energy density of batteries may cause 5-10% savings in production emissions. In addition, if electricity grids EVA which is used to charge electric vehicles were to shift from coal-based ones, emitting around 0.9 kg CO2/kWh, to renewable-dominated ones of below 0.05 kg CO2/kWh, the emissions from charging could be reduced by as much as 85%. All these indicate reasons why renewable energy integration, battery technologies, and smart policy interventions are critical for advancing low-carbon transportation systems.

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